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SOIL-WATER RELATIONSHIPS OF RICE

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CONTENTS

1. INTRODUCTION

Rice, an aquatic plant, can be adversely affected when grown under unsaturated soil moisture regime for a prolonged period. Since about 75 percent of total rice acreage in Africa is grown on unbunded and unirrigated rainfed soils, soil moisture stress can adversely affect rice growth and yield. Rice yield under optimum fertilizer and moisture conditions on experimental plots has been obtained as high as 7.0 t/ha, the mean farm yield in Africa is as low as 1.2 t/ha, and ranges from 1.4 to 3.7 t/ha in the tropics of Asia and Latin America (Table 1). The average yield of rice in west Africa is about 0.5 t/ha (Abifarin et al, 1971), although the national average is higher for many countries. Experimental station average yields of upland rice ranges from 2.5 to 3.5 t/ha in Gambia, 3-4 t/ha in Ivory Coast, 3.6 to 3.5 t/ha in the Republic of Benin, and 3 to 4 t/ha in Western Nigeria (USDA, 1968).

One of the important factors affecting rice production under upland conditions is the soil moisture stress. In shallow soils developed on basement complex rocks, and in those regions where evapo-transpiration exceeds the precipitation over 5 to 7 -day period during the growing season, shallow rooted crops such as rice can be adversely affected by frequent droughts. In addition, root growth on some soils can be seriously impeded due to adverse physical properties (high gravel concentration, compaction etc.) or nutritional imbalance (Al or Mn toxicity) (Babalola and Lal, 1976 a, b). Therefore, under dry upland conditions, rice suffers from drought stress even a few days after a heavy rain.

The problem of drought stress is a complex one, and needs to be investigated for agronomic, genetic, engineering, soil-water management and irrigation, and plant physiological aspects. Knowing soil-water relations or rice can be helpful in developing suitable agronomic practices including time of planting, methods of seed bed preparation, seeding techniques, and depth and duration of flooding. Selection of suitable varieties should be based on criterion that reflect ability to withstand drought e.g. leaf water characteristics, consumptive water use, rooting depth, and ability to produce a stable yield under adverse conditions.

There is scanty information on plant-water relations of suitable upland varieties. The realm of water management, even for irrigated or swamp rice, is still an open question. How much water? Is flooding necessary? What are, if any, advantages of mid-season drainage? Is puddling necessary?

The objective of this report is to compile the existing information on these subjects, and review the results of experiments conducted at IITA - Nigeria. The existing information will be critically reviewed with an objective to indicate gaps in our knowledge on soil-water relations of rice, and to indicate research priorities in soil and water management for rice.

This volume is deficit in terms of reviewing the research information on water use by rice for different soils and agroecological environments, land forms in relation to rice production. Since this volume was prepared in 1976, many suitable reviews have appeared in these aspects and readers are referred to those books and reviews for broader aspects of soil-rice relationship . This compilation deals with a rather narrow aspect of soil-water relations of rice and some techniques of investigating the plant-water status of two rice cultivars grown under a range of soil moisture regimes and fertility conditions.

Table 1. Rice acreage and production in the tropics (1973-1975). Adopted from IRRI, 1977).

Region	Area (1000 ha)	Area % of World total	(1000 mt)	% of World total	Mt/ha	% of World total
East Asia	39,501	28.7	146,920	44.3	3.7	154
South east Asia	32,716	23.8	67,037	20.2	2.0	83
South Asia	51,717	37.6	90,825	27.4	1.8	75
West Asia	687	0.5	1,988	0.6	2.9	121
North Africa	461	0.3	2,346	0.7	5.1	212
West Africa	2,033	1.5	2,436	0.7	1.2	50
Central and east Africa	1,708	1.2	2,523	0.8	1.5	62
Brazil	4,836	3.5	6,684	2.0	1.4	58
Other Latin American Countries.	1,806	1.3	5,301	1.6	2.9	121
World	137,411	100	331,460	100	2.4	100

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2. WATER REQUIREMENT OF FLOODED RICE

The actual transpiration, when the canopy is full and water is not limiting, may not be drastically different in flooded than in upland rice or other adequately watered upland crops. The important factors that influence the total water requirement of paddy rice include climatic parameters that influence evaporation (radiation, wind, temperature, humidity), soil properties (such as water holding capacity as influenced by texture and structure, deep seepage and percolation, depth of ground water, presence or absence of hard impermeable layer in the soil profile), methods of seedbed preparation and other cultural practices (puddling, dry seed bed preparation, direct seeding versus transplanting, fertilizer rate), varietal characteristics (including days to maturity, growth characteristics including leaf area and tillering), and the mode of water application or water management systems.

A considerable research on consumptive water use of flooded rice has been done in south and southeast Asia, and other rice growing regions of the world. A brief summary of the water requirement of flooded rice is shown in Table 1. Most of the results concerned lysimetric studies, and computations of water requirements from climatic data. There has been little available information on consumptive water use of flooded rice from West Africa.

Pan (1952, 1963) reported that in the Hunan province of China, total water requirement of paddy is about 85 cm, 55 percent of which is actual transpiration. Sahu and Rath (1972) reported that total consumptive water use ranged from 1218 to 1359 mm. In north India, Ghildyal reported from lysimetric experiments a peak rate of 14.9 mm/day for tall indica varieties and 13.1 mm/day for dwarf varieties. Mohammed and Morachan (1974) found that water requirement for Madras in India from planting to harvest was 1417 mm for IR-8 and 1217 mm for IR-20. In the Philippines, evaporation ranging from 4 to 12 mm/day has been reported by various researchers (Table 1).

Experiments reported from Japan (Leonard, 1948) indicated the water requirement of rice ranging from 70 to 131 cm. Matsushima (1960) reported the transpiration ratio for Japan to be 450. The transpiration ratio was found to be 316 for Malaysia (Sugimoto, 1972).

The consumptive water use of rice was observed to be 180 cm in the Murrumbidgee Irrigation Area of New South Wales, Australia (Hungerford, 1956), whereas in the southern USA, Jones (1934, 1938) reported that 4 to 5 acre feet of water are required to produce a crop of rice. In California, USA, Raney et al. (1961) reported evapotranspiration ranging from 2.8 to 3.0 acre feet.

The literature presented indicates that consumptive water use by rice ranges from 0.2 to 1.3 cm/day, depending on soil, climatic factors,

Table 1. Water requirement of flooded rice (mm/day).

Country	Region	Water Requirement	Reference
Australia	New South Wales	180 mm/season	Hungerford (1950)
Bulgaria	-	720 mm/season	Sparsov (1973)
China	Hunan Province	85 cm/season	Pan (1952, 1963)
India	-	1218-1359mm/crop	Sahu and Rath (1972)
India	U.P.	14.9 mm/day	Ghildyal (1973)
India	-	11-12 mm/day	Nair (1973)
India	-	1217-1417mm/crop	Mohammed and Mora-chen (1974)
India	Bihar	4.0-5.1mm/day	Chaudhry (1966)
India	Indian subcontinent	0.2-8.3 mm/day	Mukerjee and Chat-terjee (1967)
Indonesia	-	4.0-6.0 mm/day	Goor (1950)
Iran	-	8.0 mm/day	Goor (1961)
Japan	-	70-131 cm/crop	Leonard (1948)
Laos	-	5.0 mm/day	Kung and Atthayodin (1965)
Malaysia	-	5.0-5.5 mm/day	Goor (1963)
Pakistan	-	8.0-11.8 mm/day	Huang (1963)
Philippines	-	4 mm/day	IRRI (1964-65)
Philippines	-	10.4-11.6mm/day	Alfonso (1948)
Philippines	-	5.9-6.9 mm/day	Kampen (1976)
Surinam	-	7.0 mm/day	Eijsvogel (1961)
Taiwan	-	5.4-5.9 mm/day	Kan (1969)
Thailand	-	5.0-6.0 mm/day	Kung and Atthayodin (1961)

and the growth characteristics of the variety grown. The results of experiments conducted at IITA, Ibadan, and at IRRI, Los Banos, are presented in the following section, and are compared with those obtained elsewhere. The results are summarized according to the factors affecting consumptive water use of rice.

Consumptive water use at different growth stages. Generally, the peak water demand of rice is from maximum tillering to the grain filling stage. Nair et al. (1973) reported that the greatest daily ET rates occurred from maximum tillering to heading.

The evapo-transpiration of flooded rice at Ibadan, Nigeria, for three consecutive seasons is shown in Figures 1 to 4. The data in Figure 1 indicate that for the first six weeks after planting, there were no significant differences in the evaporation and evapotranspiration. The mean evapo-transpiration was 3.4 cm/week. There was a steady increase in the evapo-transpiration from the seventh week after planting, attaining a maximum rate of 7.3 cm/week occurring during the 12th week after planting. This period corresponded with the panicle development and the grain filling stage. There was a gradual decline in the evapo-transpiration rate from week 12 to maturity. The evapo-transpiration (evaporation ratio for various growth stages) is shown in Tables 2-5. During the period of peak water demand, evaporation constitutes only 30-40 percent of the evapo-transpiration. Similar results have been reported elsewhere (Sparsov, 1973; Nair et al., 1973).

Table 2. The ratio evaporation : evapotranspiration in rice paddy (August - December 1970).

Week after planting	Evaporation : Evapo-transpiration
6	0.98
7	0.98
8	0.77
9	0.69
10	0.52
11	0.34
12	0.44
13	0.30
14	0.36
15	0.35
16	0.32

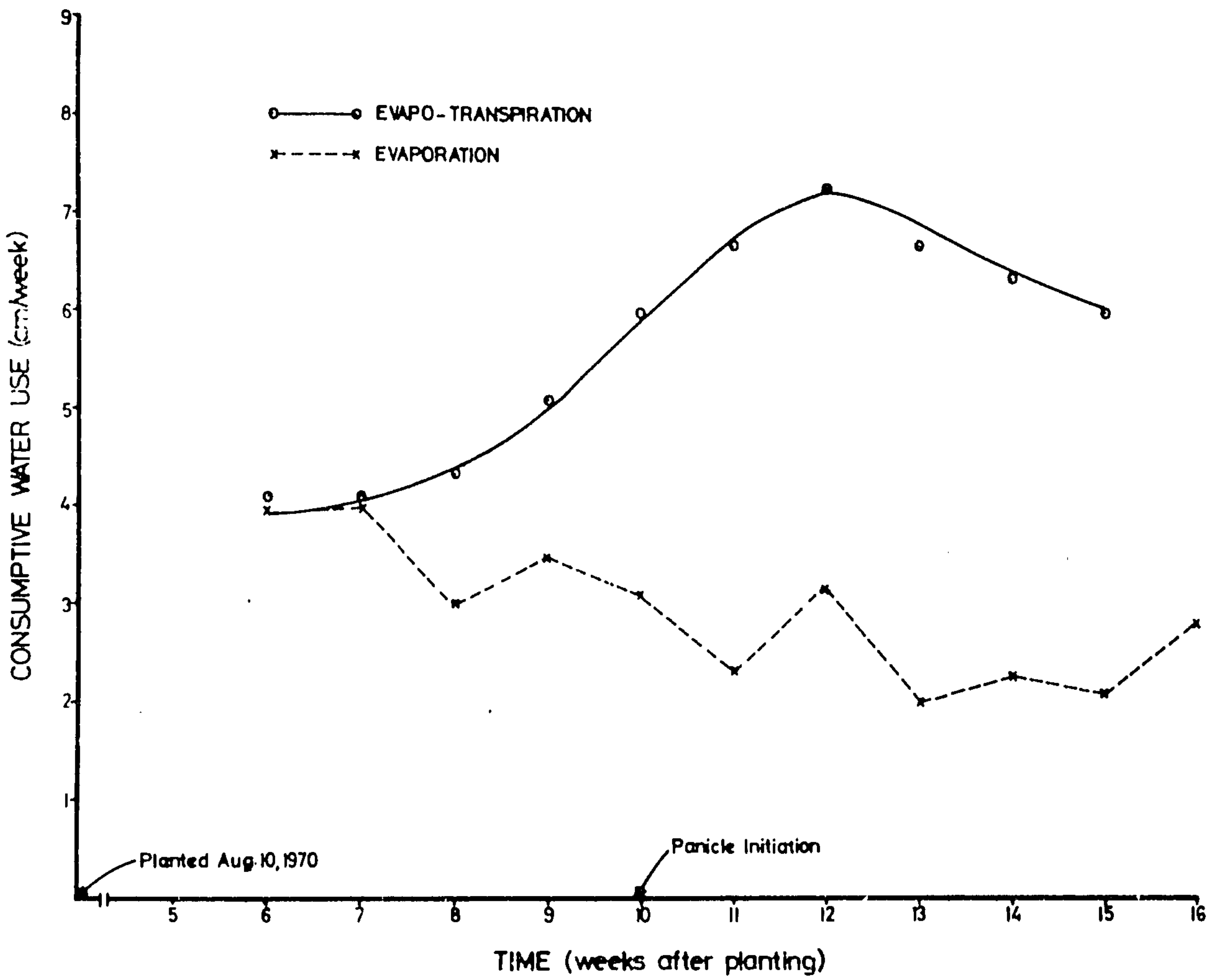

Fig.1. Consumptive water use of IR-20 at different growth stages in relation to the evaporative demand.

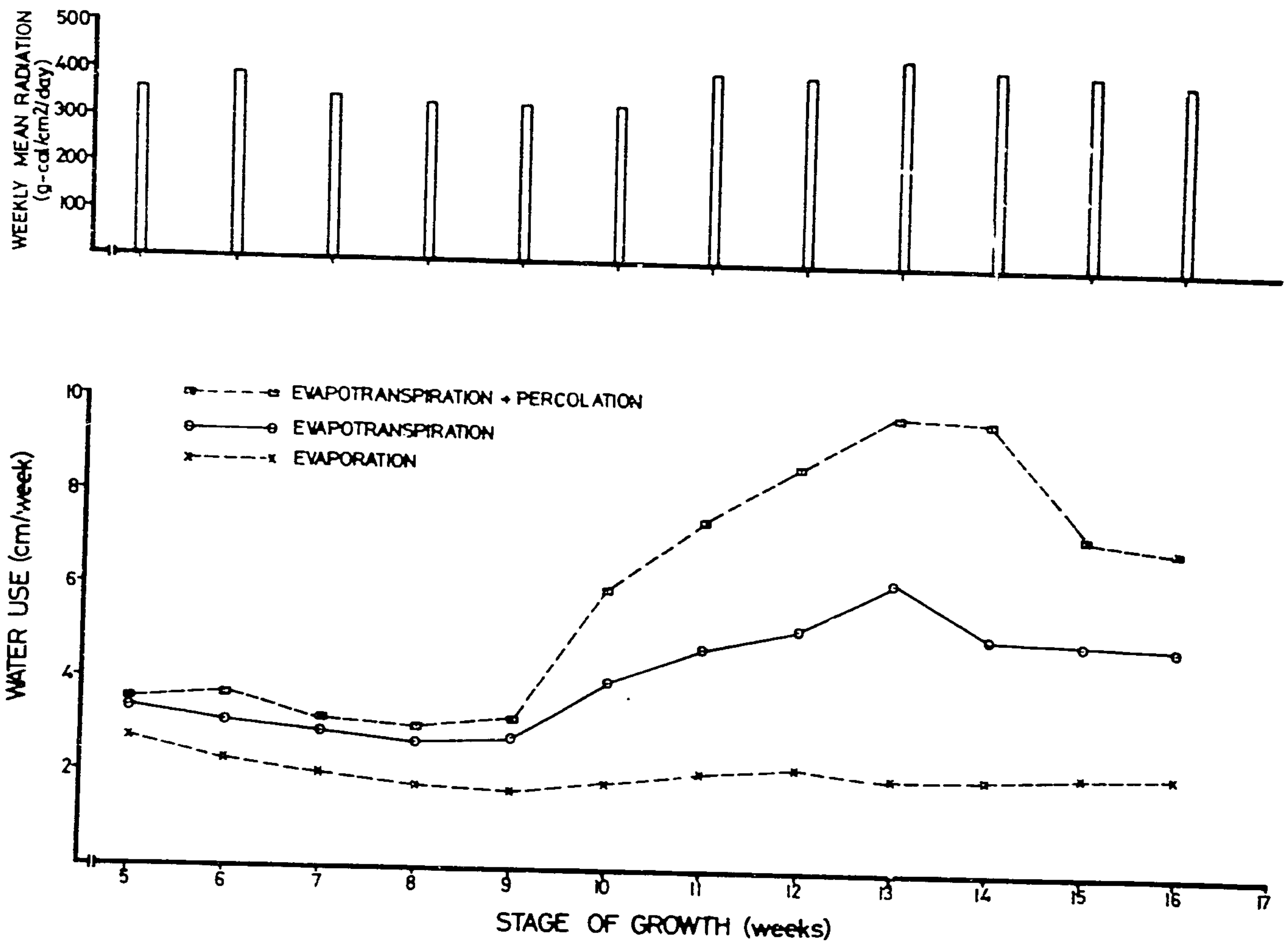

Fig.2. Water balance of IR-20 grown under flooded conditions in relation to the evaporative demand (Second Season, 1970).

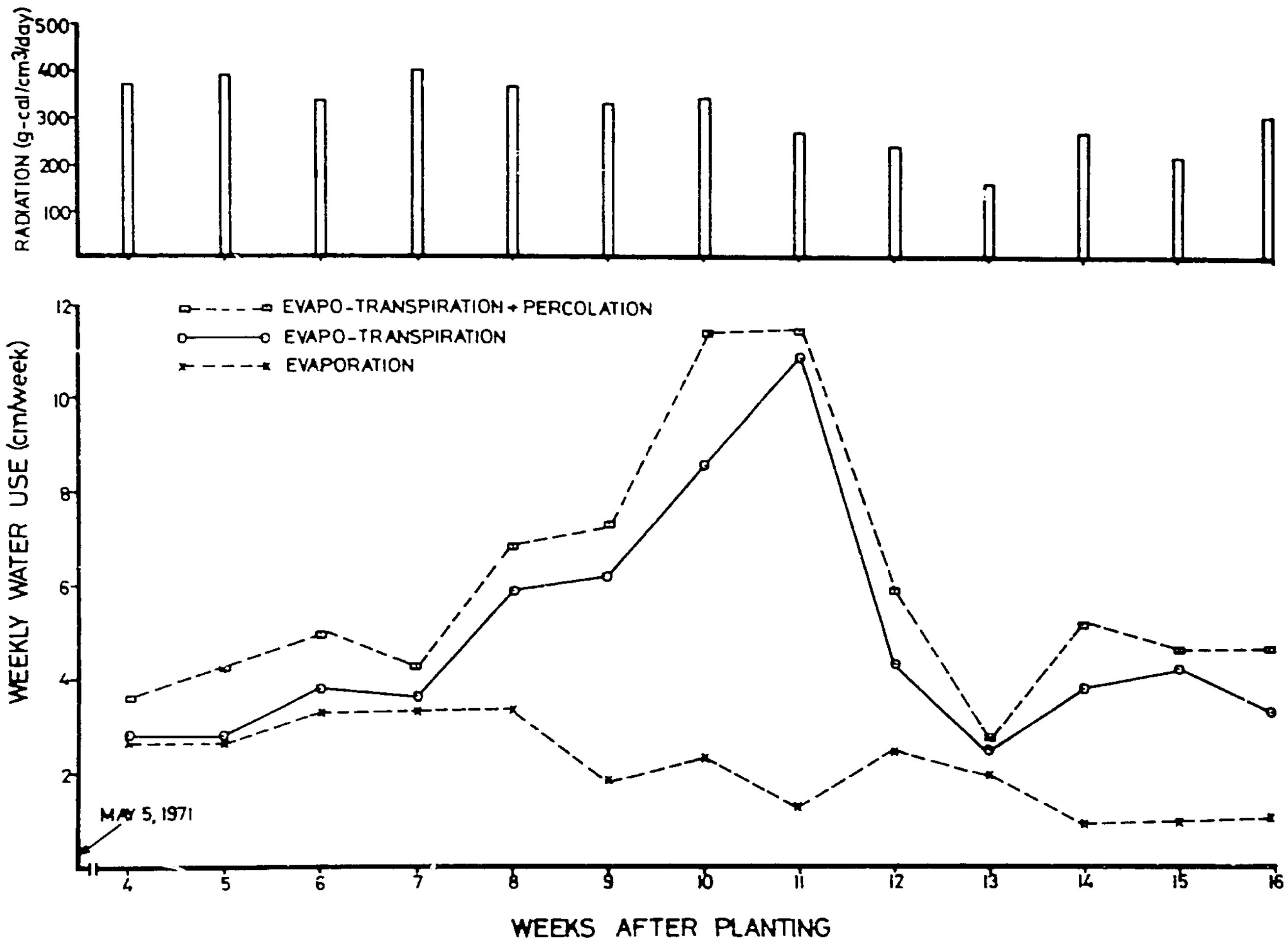

Fig.3. Water balance of IR-20 grown under flooded conditions in relation to the evaporative demand.

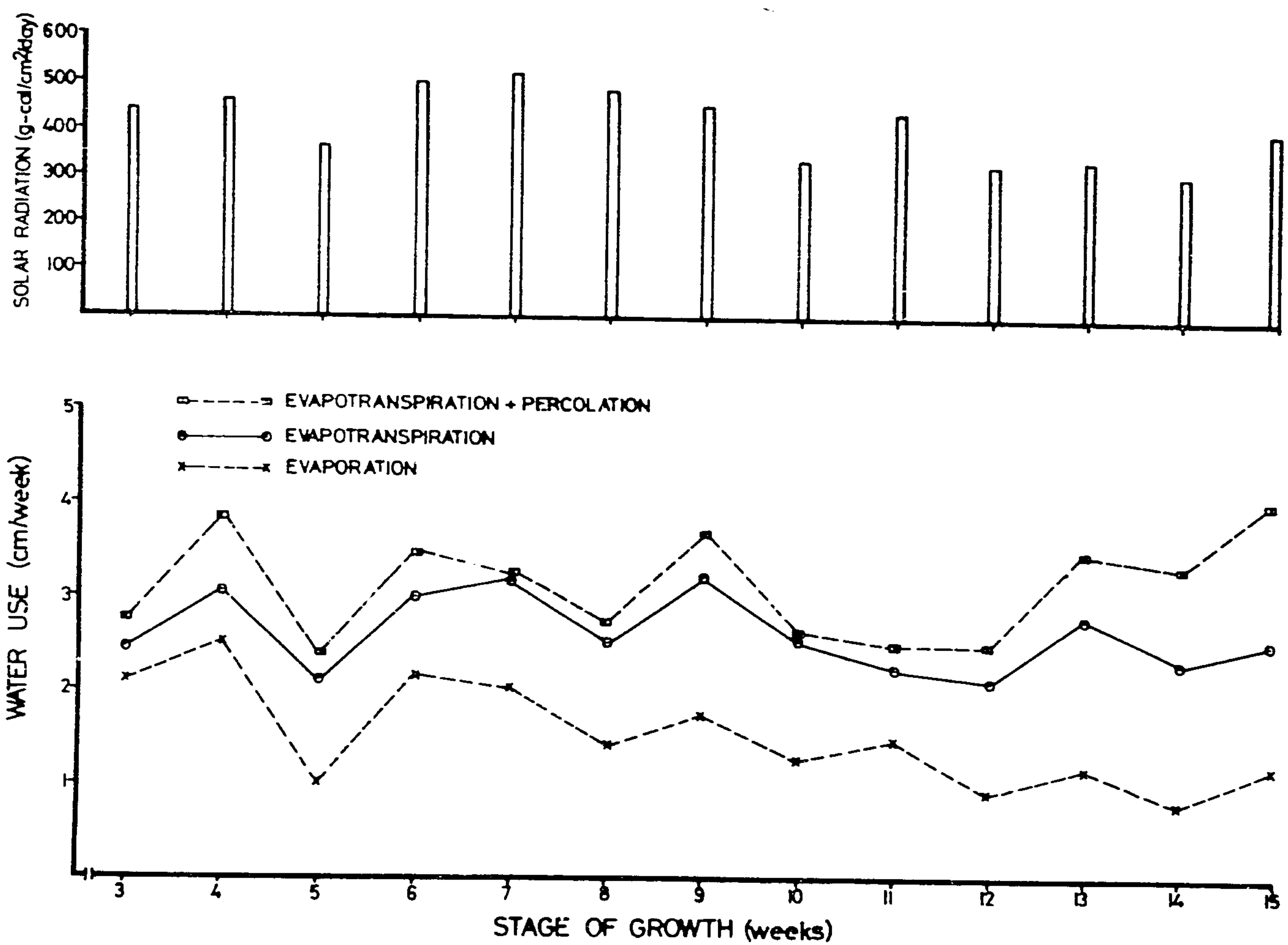

Fig.4. Water balance of IR-20 grown under flooded conditions during the dry season from November 1971 to March 1972.

Table 3. Components of consumptive water use by paddy rice (May-September 1971).

Weeks After Planting	Evaporation cm/week	Percolation cm/week	Transpiration cm/week	E/T	P/T
4	2.8	0.9	0.1	28.0	9.0
5	2.7	1.5	0.1	27.0	15.0
6	3.3	1.2	0.5	6.6	2.4
7	3.41	0.7	0.2	17.0	3.5
8	3.3	0.9	2.6	1.27	0.35
9	1.8	1.1	4.4	0.41	0.25
10	2.3	2.8	5.3	0.43	0.53
11	1.2	0.5	9.7*	0.12	0.05
12	2.5	1.6	1.8	1.4	0.90
13	1.9	0.3	0.6	3.2	0.50
14	0.9	1.4	2.9	0.3	0.48
15	0.9	0.4	3.3	0.27	0.12
16	1.0	1.4	2.3	0.43	0.61
17	1.0	1.5	4.2	0.24	0.36
Total:	29	16.2	38.0	0.76	0.43
			GRAND TOTAL = 83.2 cm		

*Lysimeters were flooded due to heavy rains.

Table 4. Consumptive water use (cm/week) for dry season crop (November 1971 to March 1972).

Weeks after planting	Evaporation (E)	Percolation (P)	Transpiration (T)	E/T	P/T
5	2.73	0.07	0.77	3.55	0.09
6	2.24	0.63	0.84	2.67	0.75
7	2.03	0.21	0.91	2.23	0.23
8	1.75	0.35	0.91	1.92	0.18
9	1.61	0.42	1.12	1.44	0.38
10	1.82	2.03	2.17	0.84	0.94
11	2.10	2.24	2.66	0.79	0.84
12	2.17	3.50	3.01	0.72	1.16
13	1.96	3.57	4.27	0.46	0.84
14	2.03	4.62	3.01	0.67	1.53
15	2.10	2.31	2.87	0.73	0.80
16	2.10	2.10	2.80	0.75	0.75
17					
Total	24.64	22.05	25.34	0.97	0.87

G.T. = 72.03

Table 5. Components of consumptive water use in paddy rice (May-September 1972).

Weeks after planting	Evaporation cm/week	Percolation cm/week	Transpiration cm/week	E/T	P/T
3	2.10	0.35	0.35	6.00	1.00
4	2.52	0.77	0.56	4.50	1.38
5	0.98	0.28	1.12	0.88	0.25
6	2.17	0.40	0.84	2.58	0.48
7	2.03	0.07	1.19	1.71	0.06
8	1.40	0.20	1.12	1.25	0.19
9	1.75	0.49	1.47	1.19	0.33
10	1.26	0.07	1.33	0.95	0.05
11	1.47	0.28	0.77	1.91	0.36
12	0.91	0.42	1.19	0.76	0.35
13	1.19	0.70	1.61	0.74	0.43
14	0.77	0.05	1.54	0.50	0.03
15	1.19	1.54	1.33	0.89	1.16
16	1.05	1.05	1.89	0.56	0.56
Total	20.79	6.68	16.31	1.27	0.41

The effects of climatic parameters on consumptive water use. The energy required for the evaporation is dependent on the changes in climatic variables. Estimates of evapo-transpiration of rice have therefore been obtained from pan evaporation. Sugimoto (1976) observed in Malaysia that the transpiration/pan evaporation and evapo-transpiration/pan evaporation ratios were constant, and were unaffected by plant growth, particularly if the leaf area index (LAI) was 3.5. Evapo-transpiration was significantly related to sunshine (r=0.72). Similar studies have been conducted in Japan by Nagahori and Amaya (1972). These researchers observed that the water consumption of 10-day periods showed the same tendency, and that the evapo-transpiration peak coincided with the temperature peak and the duration of the sunshine. Ueki and Shanmugaratnam (1973) also observed a high correlation coefficient between transpiration and daily incoming radiation. The peak transpiration occurred at about maximum tillering, also corresponding to maximum radiation values.

Vamadevan (1971, 1973) observed in India that the ratio of evapo-transpiration (ET) in a rice crop and class A pan evaporation was constant throughout the growing season. Moreover, the potential ET was significantly increased by water depth during the early period of rice growth. In Australia, Evans (1971) and Long et al. (1974) reported significant correlation between evapo-transpiration and U.S. class A pan evaporation.

Allavena (1972) compared the experimental values of ET with those calculated by the formula of Thornthwaite, Turc, Blaney-Criddle, Hargreaves, Penman, and with that from an atmometer. The estimates obtained from the formula of Thornthwaite and those obtained from atmometer deviated from the observed value from -3 to +11 percent.

The experiments conducted at Ibadan indicated significant differences between the water temperature in the evaporation pan installed within a large paddy field, and the water temperature under the rice (Table 6). In the morning (0800 hr), water temperature in the rice paddy was about 1 C lower than that in the bare evaporimeter. In the afternoon, however, the temperature under field paddy was 3-8 C lower than that in the evaporation pan. This magnitude of difference in water temperature may account for a large variation in the pan evaporation compared with evapo-transpiration from a rice field.

The correlation coefficient between evaporation, transpiration, and evapo-transpiration for different season crops at Ibadan with climatic variables is shown in Tables 7-8. The consumptive water requirement in these studies was significantly correlated with the solar radiation, stage of growth, and the LAI. The higher the leaf area, the more the evapo-transpiration. About 40 percent of evapo-transpiration was attributable to the parameters that also influence pan evaporation.

Table 6. Water temperature (^{o}C) in paddy (planted August 10, 1970)

Date	8 a.m.		4 p.m.	
	Rice	Bare	Rice	Bare
19/11/1970	25.4	26.0	27.4	34.4
20/11/1970	25.4	26.0	27.5	33.4
21/11/1970	26.0	26.7	-	..
22/11/1970	-	-	-	-
23/11/1970	25.5	26.0	27.4	33.2
24/11/1970	25.6	26.3	27.0	32.9
25/11/1970	25.3	26.0	27.3	33.3
26/11/1970	24.9	25.6	27.2	30.4
27/11/1970	23.8	24.4	26.0	33.8
28/11/1970	22.4	24.0	-	-
29/11/1970	-	-	-	-
30/11/1970	20.4	21.0	-	-
1/12/1970	-	-	-	-
2/12/1970	19.8	20.5	23.2	31.5
3/12/1970	19.6	19.9	-	-
4/12/1970	18.4	18.7	21.8	30.0
5/12/1970	18.6	19.6	-	-
6/12/1970	20.4	21.0	-	-

- = no records available

Table 7a Correlation coefficients and regression equations between consumptive water use (cm/week) and other parameters (May-September 1971).

Independent variable	Dependent variable	r^2	Regression Equation
Evaporation (E)	Evapo-transpiration (ET)	0.41	ET = -4.044 + 2.52E
LAI	Evapo-transpiration	0.53	ET = 2.9 + 0.13 LAI (4-12 weeks)
Weeks after planting	Evapo-transpiration	0.89	ET = 0.48 + 0.71 x (4-12 weeks)
Raditaion (R)	Evaporation (E)	0.49	E = -0.59 + 0.01 R
Consumptive water use (RT + P)	Evapo-transpiration	0.94	(ETP) = 0.84 + 1.06 ET
Radiation (R)	Evapo-transpiration	0.40	ET = 0.46 ± 0.0027 R

Between 10 and 16th week, and excluding rainy days.

Table 7b. Consumptive water use in relation to other climatic parameters.

(a) Mean values of various parameters

	Mean	sd	SE
Evapo-transpiration (mm/day)	4.12	2.29	0.22
Evaporation (mm/day)	2.76	2.38	0.23
Radiation (gcal cm^{-2} day^{-1})	296.6	111.6	10.94
Mean humidity (%)	85.9	5.30	0.52
Mean temperature (C)	23.7	1.23	0.12
Mean wind velocity (m hr^{-1})	0.97	0.41	0.04

(b) Table of correlation and regressions

Independent variable	Dependent variable	r	Regression equation
Evaporation	Evapo-transpiration	0.56**	Y = 2.62 + 0.54x
Radiation	Evapo-transpiration	0.53**	Y = 0.90 + 0.0108x
Humidity	Evapo-transpiration	-0.45**	Y = 20.7 - 0.194x
Temperature	Evapo-transpiration	0.48**	Y = 17.1 + 0.89x
Wind velocity	Evapo-transpiration	0.03	Y = 3.96 + 0.16x
Radiation	Evaporation	0.41**	Y = 0.17 + 0.009x
Humidity	Evaporation	-0.40**	Y = 18.16 - 0.18x
Temperature	Evaporation	0.48**	Y = -19.38 + 0.93x
Wind velocity	Evaporation	0.23	Y = 1.47 + 1.33x

Table 8. Regression equations between variables and consumptive water use (cm/day), November 1971 - March 1972.

Independent Variable	Dependent Variable	r^2	Regression equation
*Solar radiation ($g\ cal\ cm^{-2}\ day^{-1}$)	ET	0.80	ET = -0.63 + 0.0033R
Stage of growth (week)	ET	0.66	ET = 0.123 + 0.047G
Evaporation (E) (0-8 weeks growth)	ET	0.90	ET = 0.216 + 0.73E

* Between 10th and 16th week.

G - weeks after planting

Table 9. Influence of soil moisture regime on consumptive water use of rice (May-September 1971).

Moisture Regime	Consumptive water use (cm/crop)
Saturated, no ponding	60.0
Flooding, 20 DAS	44.8
Flooding, 35 DAS	50.1
Flooding, 55 DAS	31.3
Alternate flooding	39.8
Rainfed bunded free drainage	46.0
LSD (.05)	14.0

The experiments conducted at IRRI in the Philippines indicated a high correlation of daily evapo-transpiration with solar radiation ($r = 0.85$), with a mean value of solar radiation of 357 gm-cal/cm^2/day and ET of 4 mm/day (IRRI, 1964; Johnson, 1965). The results of some studies by De Datta et al. (1968) indicated that the correlation between the evapo-transpiration and solar radiation was significant ($r = 0.65*$). Obviously the solar radiation was not the only factor responsible for the evapo-transpiration losses. The evapo-transpiration/evaporation ratio was $\frac{445 \text{ mm}}{271 \text{ mm}} = 1.6$ for the rainy season of 1968.

<u>The effects of soil moisture regime and mode of irrigation</u>. The method of irrigation, depth of submergence, and plant population have a significant effect on consumptive water use of rice. Leonard (1948) observed in Japan that rice did better if the water is deep immediately after transplanting and shallow at tillering stage. Hagahori and Amaya (1972) also reported from Japan that the water consumption on the dried field was about three times as high as on the ponded field. On the contrary, Pande and Mitra (1971) reported from India that the transpiration, evaporation and percolation losses all increased with the level of submergence.

Experiments conducted at Ibadan indicate a significant effect of soil moisture regime on consumptive water use (Table 9). The maximum consumptive use was recorded for continuously ponded treatments. Withholding flooding until 55 days after planting also reduced the consumptive water use. Consumptive water use of rainfall rice of 46 cm was also identical to treatments where submergence was observed. This implies that under rainfall conditions similar to that of Ibadan, a successful rice crop under hydromorphic (valley bottom) soils can be grown without supplemental irrigation.

<u>Effect of land preparation methods on consumptive water use</u>. Bradfield (1970) suggested that a desirable alternative to soil puddling for rice cultivation might be the practice of furrow irrigation for growing rice on non-puddled soil. Experiments have been conducted at IRRI to evaluate the effects of this alternate system on consumptive water use and grain yield of rice. The water required for land preparation in the lowland field was estimated to be 150 mm, and that in the non-puddled field was only 75 mm. The daily rate of water use was 7.71 mm/day and 3.37 mm/day for the puddled and non-puddled treatments, respectively. Averaged over the whole growing season, the consumptive water use of the non-puddled field was only 44 percent of that from the puddled field. Similar results of the water requirements for land preparation in the Philippines have been reported by Kampen (1970).

Summary

The consumptive water use of rice depends on factors such as climate, variety, leaf area index, growth duration, method of irrigation, depth of submergence and land preparation. The results of consumptive water use, therefore, vary from region to region. The evapo-transpiration of rice can be approximately estimated from the data of solar radiation and pan evaporation. However, the empirical relations have to be experimentally developed for each region. The evapo-transpiration/evaporation ratio is generally constant for a given region.

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3. EFFECTS OF DIFFERENT SOIL MOISTURE REGIMES IN PADDY ON GROWTH, YIELD OF RICE

Traditionally rice is grown in flooded soil, with irrigated rice accounting for 40 percent of total rice production in south and southeast Asia (Barker, 1970). The system of flooding rice is widely practiced, although reasons are complex and not well understood. Weed control when submerged is one such reason. Depending on soil factors, fertilizer efficiency and nutrient availability may also be better under flooded than under upland conditions. With the economical availability of herbicides, however, the role of flooding and even puddling for weed control is now questionable. This subject will be discussed in other chapters.

A considerable amount of research on the effects of flooding and mid-season drainage on rice has been done in Japan. Yoshino and Kawasaki (1953) reported from their studies on directly-sown rice that flooding from sixth-leaf stage gave the highest grain yield. These findings were supported by subsequent experimentation by Amatatsu et al. (1954) who observed that irrigation in the initial stages resulted in a vigorous growth only in the vegetative stage of crop growth. Withholding irrigation in the initial stages suppressed vegetative growth, but the grain yield was 10 percent higher than in the continuously submerged treatment. The research conducted by Arashi (1955) and Baba (1956) (reported by Yamada, 1964) indicated that midseason drainage produced 30 percent more grains than the undrained plots. The highest grain yield was obtained by withholding the water supply from 25-35 days before heading. Koyema et al. (1960) also observed that drainage of paddy fields at floral initiation stage favored more tillers per plant than fields under continuous submergence. Miyasaka (1970) reported that drainage reduced the water content of leaves, increased the N uptake by the roots (as a result of increased root activity), increased the photosynthetic activity during ripening stage, and consequently increased the grain yield. The time at which paddy was drained between tillering and heading stages also affected the distribution of carbohydrates (source/sink relationship) but not the final grain yield. Hashimoto (1970) reported that surface irrigation gave higher yield than continuous flooding for a clayey soil.

The experiments conducted in South Asia have produced results which cannot be generalized. Chaudhry and Pandey (1965) reported the highest yield for submergence up to 10 cm depth till flowering stage followed by drainage. Tomar et al. (1971) reported the highest yield under continued submergence. Singh and Pande (1972) conducted field experiments to compare grain yields from continuous submergence (10 to 15 cm), cyclic submergence (0 to 15 cm), cyclic wetting-drying (between saturation and field capacity) with that of natural precipitation. Continuous submergence gave the highest yield. Upadhya and Datta

(1973) reported only a slight decrease in rice yield by midseason drainage. Nagarajah et al. (1973) reported from Sri Lanka that when IR-22 was either continuously flooded or drained for 2-10 days at primordial initiation, the drainage did not increase rice yield during either of the two growing seasons. Sheikh (1973) reported that the best growth was obtained with continuous flooding of the soil. A combination of drainage for four weeks followed by flooding for eight weeks resulted in chlorotic plants and poor growth. The increase in the Fe concentration in the plant tissues following flooding was correlated with the best growth (flooded treatment), unless it was accompanied by high Mn levels (drained and flooded treatment) which proved toxic. The work done in India on this aspect has indicated that non-submergence of rice fields was detrimental to the yield unless the soil profile was saturated or partially saturated (Ali et al., 1974). On the other hand, Kanwar et al. (1974) found that the best yield of rice was obtained when the soil moisture regime was between saturation and a suction of 0.15 atmosphere, as compared with that of flooding to a depth of 2.5 to 7.5 cm of water. The work of Jha et al. (1975) attributed the benefits of flooding to uptake of Fe and Mn. They concluded that land submergence could perhaps be dispensed with, if these nutrients were foliar applied, provided the soil was kept moist (suction not exceeding 0.3 bar) and there was good weed control.

Research has also been conducted in other sub-tropical or tropical regions to investigate the optimum moisture regime of rice. Bulanadi and Aldaba (1958) reported higher plant height and yield for intermittent irrigation compared with those of continuous irrigation. In Brazil, Bernardes (1958) showed that draining the fields 20 to 30 days after emergence, and until the plants showed signs of wilting, produced the highest grain yields. Experiments conducted in Jordan (1958) showed that rice yields were directly related to the water supply at all stages of growth. Bulandi et al. (1958 and 1959) produced contradictory results in two separate studies. Hall (1959) concluded from his experiments that the advantage of draining rice fields is the ease of fertilizer application. Enyi (1963) found that the critical period for waterlogging of rice was four weeks after transplanting and that water logging 4-8 weeks after transplanting favored higher grain yields than did earlier waterlogging. Grist (1965) has maintained that paddy should be planted in a properly soaked field and that the depth of the water should be increased with plant growth until the depth is 15-30 cm of water. Palada and Vergara (1972) reported that the survival of rice seedlings after complete submergence decreased with increasing duration of submergence.

A critical appraisal of the literature reported indicates that soil should be kept near saturation for optimum rice growth. The beneficial or harmful effects of drainage at various stages of growth depend on several interacting factors including soil properties, nutrient status and soil composition, weed infestation, climatic conditions and the history of the field itself, in addition to significant varietal differences.

The effects of depth of flooding has also been investigated by numerous researchers. Bulandi et al. (1959) did not find any difference in rice yield for five submergence depths from 0 to 20 cm. Pande and Mitra (1971) observed that under three levels of submergence (0, 5 and 10 cm depth) the highest evapo-transpiration corresponded with the highest submergence depth. Sahu and Rath (1972) found that yield reduction of 12-24 percent occurred when the depth of submergence was decreased from 10 to 7.5 and to 5 cm, respectively. Experiments conducted in the Philippines by Sanchez (1973) to determine the factors responsible for beneficial effects of puddling and submergence, indicated that the advantages of puddling tropical soils are directly or indirectly related to decreasing water losses and not to increasing the nutrient supplying capability of the soil. In general, puddled flooded treatments produced yields similar to other treatment combinations. Gorantiwar et al. (1973) observed no differences in rice yield between two submergence depths of 4 and 7 cm of water. Similar results were reported by Singh et al. (1973) and Moraes and Freire (1974).

The results of water management experiments conducted at IITA, Ibadan, on sandy loam Alfisol are compared in the following section with those obtained at IRRI, Philippines, on heavy soil with vertic characteristics. The experiments at IITA were conducted on field lysimeters. The chemical characteristics of the soil are shown in Appendices (See pg 276). The results of water treatment on plant growth and grain yield are discussed below.

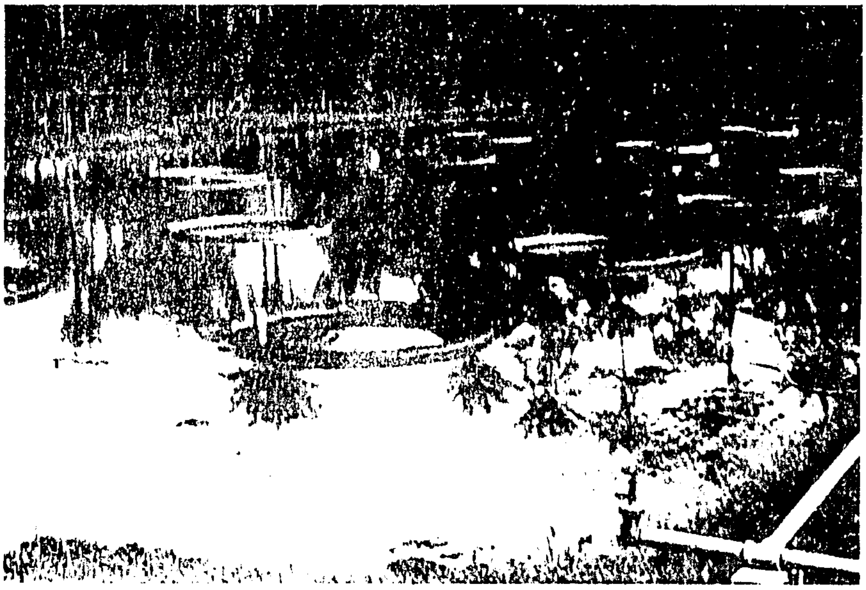
(i) Plant height and tillering behavior

Plant height at different growth stages is shown in Table 1. Plant height was not significantly affected by various moisture regimes, although the lowest height was obtained in lysimeters with a moisture regime involving soil near saturation but no submergence. Generally, plant height was higher in submerged and in lysimeters with cyclic submergence treatments.

Tiller count, however, was significantly affected by different soil moisture regimes (Table 2). The maximum tiller count was observed in lysimeters with no submergence and in rainfed treatment. It is apparent that submergence may slightly increase the plant height, but it suppresses the tillering capacity of rice. Similar observations were made in the greenhouse studies, reported in Chapters 6 and 7.

(ii) Leaf area index (LAI)

Table 3 presents the data of the leaf area per hill as influenced by different moisture regimes. The leaf area was significantly different amongst various moisture treatments, and it increased with the length of period for which the plants were submerged. The lowest leaf area was measured in the rainfed treatments, and the highest in the treatments with flooding continued from the initial stages of growth.



(1)

(2)

Plate 1. Field Layout of the lysimetric set up.

Plate 2. Microclimate measuring equipment.

Table 1. Plant height (cm) at different DAS (IR-20).

Treatment	Plant height (cm) at different days after seeding										
	25	32	39	46	53	60	67	74	81	88	95
Saturated soil, no ponding	38	46	55	70	78	85	94	96	101	107	114
Flooding 20 DAS	43	55	70	80	92	95	104	108	108	117	122
Flooding 35 DAS	38	50	60	75	83	91	98	102	107	112	123
Flooding 55 DAS	35	43	51	67	76	84	93	96	103	109	116
Cyclic submergence	40	57	66	79	90	94	99	105	110	116	124
Rainfed (bunded)	37	46	56	71	78	86	92	93	100	108	117

Table 2. Tiller count (per m^2) as influenced by different soil moisture regimes (IR-20).

Treatment	Tiller count (no/m^2) at different days after seeding										
	25	32	39	46	53	60	67	74	81	88	95
Saturated soil, no ponding	30	70	1340	1600	1780	1710	1870	1870	1760	1810	1800
Flooding 20 DAS	50	90	1200	1610	1720	1640	1550	1660	1710	1690	1690
Flooding 35 DAS	40	70	1530	1770	1870	1780	1690	1680	1640	1680	1670
Flooding 55 DAS	40	60	1370	1670	1860	1910	1870	1920	1800	1810	1800
Cyclic submergence	50	70	1190	1440	1640	1620	1550	1830	1650	1660	1650
Rainfed (bunded)	40	60	1490	1900	1900	2150	2120	1830	1780	1800	1800

Table 3. Leaf area (cm^2/hill)

(a) Maximum tiller stage (35-50 DAP)

Plant or hill	Saturated, no ponding			Flooding 20 DAS			Flooding 35 DAS			Flooding 55 DAS			Alternate flooding			Rainfed		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1	1674	259	834	3470	863	691	1008	849	1235	1528	1871	400	2471	909	535	347	347	1198
2	1557	503	1145	338	1828	558	1227	669	1274	1421	331	382	1443	449	306	2004	437	589
3	1987	646	224	2094	754	989	859	1014	864	1162	1892	462	981	589	792	462	809	305
4	1872	425	531	2608	781	3853	1234	1501	904	1107	506	327	2268	225	1342	2821	476	444
Σ	7091	1833	2733	8510	4226	6090	4327	4033	4278	5217	4600	1571	7163	2171	2974	5632	2069	2535
Mean		971			1569			1053			950			1026			853	

(b) 50% flowering stage

Plant or hill	Saturated, no ponding			Flooding 20 DAS			Flooding 35 DAS			Flooding 55 DAS			Alternate flooding			Rainfed		
1	1053	864	252	1121	870	744	629	229	2416	757	966	733	1326	385	863	758	877	1532
2	851	811	629	918	1526	1619	1698	2852	759	649	832	434	1022	1070	1667	481	763	1412
3	876	867	768	1659	2299	1339	708	917	865	680	1087	414	1891	980	1397	768	1224	1155
4	986	1422	812	699	952	610	1991	1028	1493	2129	2065	532	1172	1677	1227	599	682	1088
Σ	3766	5964	2460	4396	5647	4313	5025	5024	5532	4214	4950	2114	5410	4112	5155	2607	3546	5233
Mean		1016			1196			1298			940			1223			949	

The analyses of the vegetative growth parameters, including plant height, leaf area index and tiller count, indicate that slight moisture stress, or perhaps non-submergence with soil kept near saturation, increases tillering tendency. Whether or not these tillers are productive depends on soil moisture and nutrient supply during reproductive phase of growth. While the plant height and perhaps the number of leaves per shoot may decrease with non-submergence, the total number of shoots itself increases. The influence of non-submergence on the leaf area index (LAI) is therefore the result of many various factors.

(iii) Dry matter production at various growth stages

Dry matter production as influenced by moisture regimes for various growth stages is shown in Figure 1. Dry matter production at 90 days after planting was in the order: submergence 20 DAP > cyclic submergence > submergence 35 DAP > rainfed > saturated soil, no submergence > submergence 55 DAP (Table 4). There were no differences in the dry matter production amongst various treatments at initial stages of crop growth.

(iv) Grain and straw yield

Grain yield (Table 5) was significantly affected by moisture regimes. Grain yield was inversely related to plant height and dry matter production. The treatments which produced less vegetative growth produced more grains. As long as the soil was kept near saturation and free of weeds, delayed submergence produced high grain yield. Similar results have been reported by other workers (Amatsu et al., 1954; Bulanadi et al. 1958; Yamada, 1964; Singh and Pande, 1972; Kanwar et al., 1974; Jha et al., 1975). The influence of soil moisture regime on straw yield is shown in Table 6. Treatments with submergence from the initial stages produced higher straw yield than those treatments with delayed submergence, and when soil was near saturation during the periods of no submergence. The grain/straw ratio was 0.27, 0.39, 0.51, 0.59, 0.60, and 0.67, respectively for submergence 20 DAP, cyclic submergence, submergence 35 DAP, rainfed, saturated soil with no submergence, and submergence 55 DAP.

The influence of soil moisture regimes on other yield components such as panicle length, number of grains per panicle, floral sterility and weight of 1000 grains is shown in Table 7. Number of grains per panicle and panicle length were affected by soil moisture regime in the order similar to that of total grain yield. The computations of water use efficiency, the grains produced per unit of water consumed, differed significantly amongst various treatments (Table 8). The highest water use efficiency for grains was obtained for the treatment with submergence deferred until 55 DAP. The treatments next in this order were rainfed and that with submergence deferred until 35 DAP.

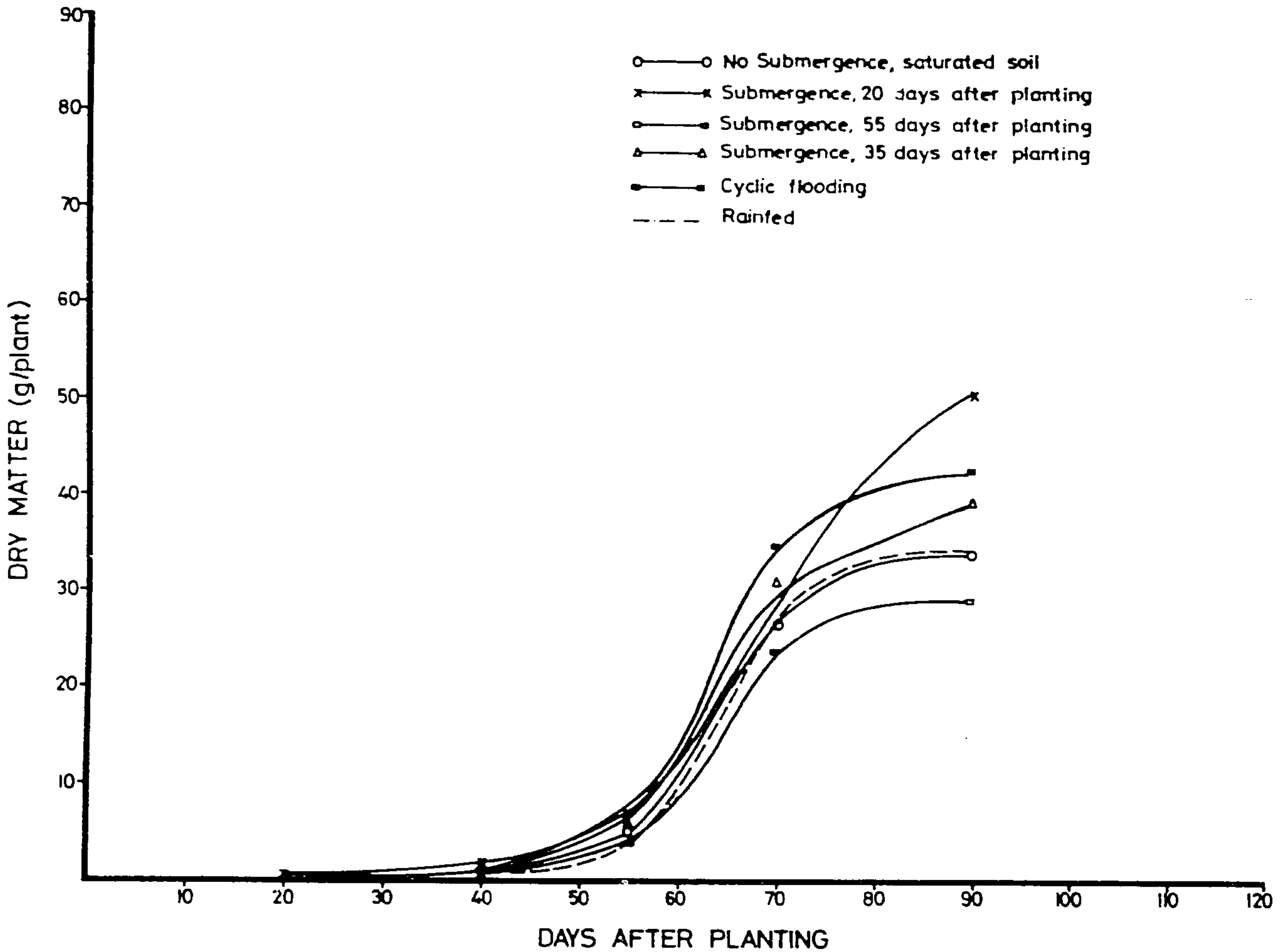


Fig.1. Effects of soil moisture regime on dry matter production of IR-20 at different growth stages.

Table 4. Influence of soil moisture regime on dry matter production of IR-20 paddy (1971).

Yield parameter	Moisture regime						LSD (.05)
	1*	2	3	4	5	6	
Mean plant height (cm)	115.3	114.4	109.6	110.9	118.8	112.1	9.3
Dry matter 40 DAS (g/plant)	1.92	1.67	1.25	1.37	1.14	1.26	0.80
Dry matter 55 DAS (g/plant)	7.13	6.02	4.52	4.88	4.29	4.57	2.74
Dry matter 70 DAS (g/plant)	32.33	28.54	22.16	31.93	23.56	23.06	9.50
Dry matter 90 DAS (g/plant)	45.60	36.02	26.48	38.46	31.05	30.24	12.4
Grain yield 90 DAS (g/plant)	5.44	3.63	2.79	4.66	3.58	4.04	2.32

*For description of treatment number, see Table 5, below.

Table 5. Influence of soil moisture regime on rice grain yield (May-September 1971).

Treatment	Grain yield (t/ha)
1. Saturated soil, no submergence	3.43 a b
2. Submergence, 20 DAP	2.26 a
3. Submergence, 35 DAP	3.82 a b
4. Submergence, 55 DAP	4.34 a b
5. Cyclic submergence	2.35 a b
6. Rainfed (bunded)	3.63 a b
LSD (.05)	1.51

Table 6. Influence of soil moisture regime on straw yield in rice (May-September 1971).

Treatment	Straw yield (t/ha)
Saturated soil, no submergence	5.69 a
Submergence, 20 DAS	8.22 a b
Submergence, 35 DAS	7.45 a b
Submergence, 55 DAS	6.51 a b
Cyclic submergence	6.00 a b
Rainfed (bunded)	6.18 a b
LSD (.05)	2.08

Table 7. Influence of soil moisture regime on yield components of rice paddy (May-September 1971).

Treatment	Panicle length (cm)	Number of grains per panicle	Floral sterility (%)	Weight of 1000 grains
Saturated soil, no submergence	26.4	172	22.4	19.3
Submergence, 20 DAS	24.5	154	21.9	19.7
Submergence, 35 DAS	27.6	148	27.0	19.0
Submergence, 55 DAS	26.0	158	21.4	18.7
Cyclic submergence	26.9	153	26.7	19.0
Rainfed (bunded)	26.0	156	19.3	20.7
LSD (.05)	1.8	39	4.4	

Table 8. Water use efficiency of rice as influenced by soil moisture regime (kg of grains/mm of water), May-September 1971.

Treatment	Water use efficiency (kg/mm)
Saturated soil, no submergence	5.72
Submergence, 20 DAS	5.04
Submergence, 35 DAS	7.62
Submergence, 55 DAS	13.87
Cyclic submergence	5.90
Rainfed (bunded)	7.89
LSD (.05)	5.0

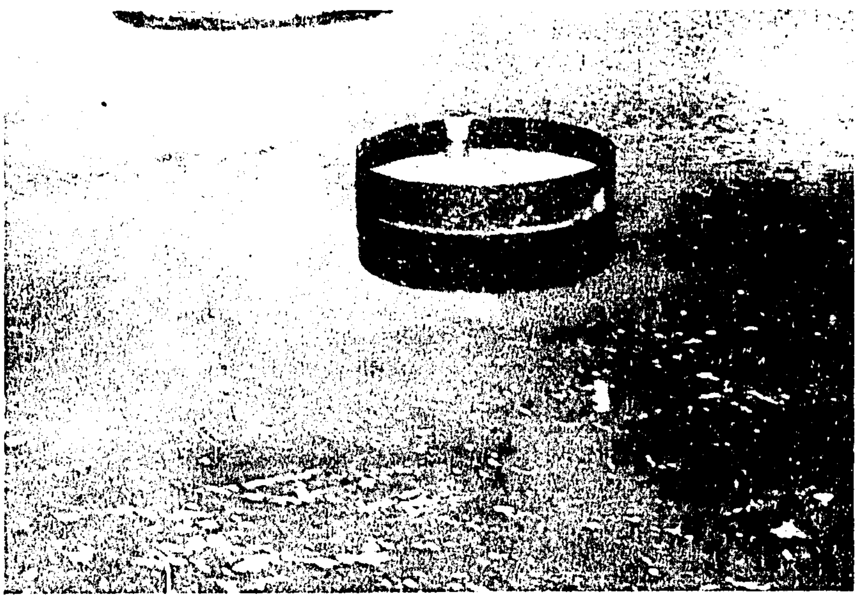


Plate 3. Pan evaporimeter installed in the field.

The experiments conducted at IRRI gave results similar to those obtained at IITA. In an experiment conducted during the 1968 wet season, IR-8 produced similar yield under rainfed and flooded paddies. H-4, a tall variety, produced more yield under rainfed than under continually flooded conditions. There was a fairly high percentage of unfilled grains and a low grain/straw ratio in H-4 under shallow and deep continuous flooding because of severe lodging. The unit grain weight, however, was not affected by water management treatments.

The most satisfactory regime in terms of grain yield was the intermediate continuous flooding. Water use efficiency, liters of water required to produce 1 gm of grain, was highest when the soil was kept at continual saturation. Drainage at maximum tillering and panicle initiation reduced water use rather than increasing grain yield.

An increase in the depth of submergence decreased the number of plants/m^2 in an experiment conducted at IRRI. The plants grew taller and the number of tillers and the panicles per unit area was reduced, though lodging at harvest was much greater in the deep flooded plots. Mid-season drainage at the maximum tillering, panicle initiation, and heading stages reduced lodging, but increased weed population.

General discussions

One of the main advantages of continuous submergence of rice is the weed control, though there is a general belief that a small amount of nitrogen fixation also occurs under continuous submergence (Watnabe, 1975). If weed control is not a serious problem and water control can be provided to ensure a saturated profile, then continuous submergence is not only unnecessary but can also have some deleterious effects on grain yield.

As shown in the literature review, the beneficial aspect of draining the rice field is also a controversial issue. The advantages of deferred submergence, however, are well documented and can be partially attributed to a better utilization of nitrogenous fertilizers. Fertilizer losses can be particularly significant for a sandy soil where leaching losses of nitrogen are likely to be high under saturated flow due to positive hydraulic head under continuous submergence. Nitrogen losses under field conditions at IITA were obvious, because it was necessary to make a frequent application of fertilizer to meet the nitrogen demand. This can be one of the reasons for a significant increase in grain yield when flooding was deferred until 55 DAP. Similarly, the higher yields under cyclic submergence, saturated soil with no submergence, and submergence 35 DAP over that of continuous submergence may be attributed to an efficient utilization of applied fertilizer. This is further evidenced by the analysis of the grain yield components and straw yield under different soil moisture regimes.

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4. INFLUENCE OF WITHHOLDING IRRIGATION ON GROWTH AND DEVELOPMENT OF RICE

The majority of rice grown in the world is rain fed. Without adequate facilities for irrigation, even paddy rice suffers from water stress during dry periods. Most of the rice (upland) grown in West Africa suffers from frequent droughts. Rice yield is low under these conditions. The adverse effects of soil moisture stress on rice are related to the functions of water within the plant. Water is needed as: (1) a constituent to cell protoplasm, (2) a reactant or reagent for chemical actions, (3) a solvent for organic and inorganic solutes and gases and (4) for providing mechanical strength to plants. Only 5 percent of the water absorbed is needed for these vital processes (Kramer, 1969). Ninety-five percent of the water absorbed is lost through the process of evapo-transpiration.

Although the literature is full of research done on various aspects of plant-water relationships (Kramer 1959, 1969; Slatyer 1960, 1962; Vaadia 1961; Penman 1963; Gardner 1965; Salter and Good 1967; Jacobs et al (Ed) 1974; Van Keulen, 1975), little has been done on the practical aspects of the problem. The results available cannot be often generalized because of the insufficient information obtained on the physical environments in which experiments were conducted. For example, an experiment designed to investigate the effect of soil-moisture stress is incomplete if it does not include monitoring the relevant characteristics of soil, plant and micro-climatic environments of its immediate vicinity. The plant response to soil moisture regime is not only a function of the availability of soil moisture, but also of the physico-chemical properties of soil, climatic conditions, nature of the leaf canopy and stomatal structure, in addition to the treatments imposed by the researcher.

The study of the influence of soil moisture stress on rice growth has attracted the attention of various researchers. It has been well known that drought stress depresses rice yield, particularly if it occurs during the flowering stage. There also exists a critical drought stress for optimum rice growth. When the duration and the magnitude of stress exceeds this critical limit, only then does there occur a significant detrimental effect toward the economic components of rice production. This "critical soil moisture potential", of course, depends on various factors, including soil characteristics, genotype, and the evaporative demand of the atmosphere. It is, nevertheless, important to identify the critical levels of moisture stress for important cultivars or genotype.

Bhatia and Dastane (1971) reported that soil moisture tension of 0.4 atmosphere caused significant yield reductions as compared with continuous submergence with 4-8 cm of standing water. On the other hand, Draganov et al. (1971) observed that continuous submergence was not necessary, and that when rice was grown at 80 percent of the soil field capacity, the total plant weight on the 18th and 23rd day was 30 and 50 percent higher respectively than when rice was grown at full field capacity. Much useful work along these lines has been reported by Ghildyal from India and other researchers elsewhere (Ghildyal, 1971; Krupp, 1971; Saha et al., 1973; Naphade and Ghildyal, 1974; Sharma et al., 1975). Jana and De Datta (1971) also found that the optimum soil moisture conditions for high yields is between the maximum water holding capacity and the field-soil moisture capacity. Similar results have been reported by Kalyanikutty et al. (1970), Mane and Bastane (1971), and Naphade and Ghildyal (1974).

There can be various reasons for the yield depressions as a result of drought stress. Many researchers have attributed yield decrease to a reduction in the uptake of essential nutrient elements under the condition of deleterious levels of drought. For example, Pande and Singh (1970) observed that the concentrations of N, P, Fe and Mn in plants were the highest under continuous submergence compared with the stressed treatments. Borantiwar et al. (1973a, b) reported from a pot experiment with black soil that zero drought stress, 300 cm of water suction and 700 cm of water suction suppressed the uptake of P and K. Saha et al. (1973) reported greater uptake of P, K, Zn, Fe and Mn under submerged conditions. Similarly Naphade and Ghildyal (1974) attributed yield reductions under drought stress to a decreased availability of N, P, K and Fe. Obermueller and Mikkelsen (1974) reported that flooded plants absorbed more P, Fe and Si than non-flooded treatments under drought stress, and that the latter showed higher accumulation of K, Mn and Zn. Sharma et al. (1975) also reported that flooding generally resulted in higher uptake of nutrients.

The beneficial effects of optimum moisture regime have also been attributed to superior leaf index area (Singh and Pande, 1974) over the plants which had been subjected to drought stress. Many researchers have attributed yield depressions by drought to its influence on the root system of rice plants (see Chapter 10). Pradhan et al. (1973) reported that root porosity was higher under submergence, though root length increased with increasing moisture tension at 0-1000 millibar suction. Sharma et al. (1975) found higher CEC of the roots with saturated soil conditions than when the soil was maintained at its field capacity.

Because the actual consumptive water use of rice plant is not more than other upland crops grown under similar soil and environmental conditions (Chapter 2), various workers have attributed the beneficial effects of saturated soil conditions on rice to the anaerobic conditions in its rooting media. Verade, Letey and Stozy (1971) observed a trend toward increasing tiller production under low levels of aeration, though O_2 level did not have a significant effect on root porosity. However, the amount of water necessary per unit dry matter production was higher under lower O_2 conditions. Naphade and Ghildyal (1974) reported that rice growth and yield were optimum in the semi-aerobic conditions.

Although the literature reviewed indicates some factors affecting yield depressions due to drought stress, this does not point much toward the critical level of soil moisture suction that can result in significant yield reductions. The results of experiments conducted at IITA and IRRI on soil moisture stress and crop response follow.

At IITA, the characteristics of the soil used in the greenhouse experiments are shown in Appendices 1 and 2. The records of daily evaporation and weather records under the greenhouse conditions are shown in Appendices 3 and 4. Some results are also shown in Appendices 5-19.

The cumulative soil moisture stress was computed for each of the unsubmerged treatments by measuring area under the curve of a plot of daily mean tensiometric reading during the growing period. The unit of this cumulative stress is referred to as cm-days.

There were significant effects of moisture regimes and plant varieties on most of the growth parameters evaluated. The analysis of variance table of F ratio for different parameters is shown in Table 1. It is apparent from the data that grain and straw yield, unit weight of grains, number of grains per panicle, tiller count, floral sterility, number of days of maturity, root weight and leaf area are significantly affected by soil moisture regime. The varietal effect is also highly significant for unit weight of grains, panicle length, straw yield, tiller count, root length and weight. The unit grain weight, root length and weight, straw yield and panicle length are higher for OS6 variety than that of IR20 under greenhouse conditions. IR20, however, has a higher tiller count than OS6. The interaction between water regime and the variety is significant only for tiller count and the number of days to maturity.

Consumptive water use. The total amount of water required in a rice crop as influenced by the soil moisture regime is shown in Figure 1. The evapo-transpiration decreased exponentially with increasing level of soil moisture stress. There were significant varietal differences in the evapotranspiration of OS6 and IR20 under the same level of soil moisture stress. Because OS6 is a tall leafy variety, its evapo-transpiration was significantly more than that of IR20.

Plant height. Plant height of IR20 and OS6 under different soil moisture regimes is shown in Table 2. Although OS6 is taller than IR20, the relative decrease in plant height with increasing level of soil moisture stress was greater for IR20 than that of OS6. OS6 maintained superior vegetative growth at all levels of soil moisture regimes investigated.

Leaf area and tiller count. Because the bigger leaf area of OS6 was partially compensated for by lower tillering capacity, its total leaf area was not significantly more than that of IR20 (Table 3). Total leaf

(1)

(2)

Plate 1. The central perforated irrigation tube

Plate 2. Irrigation was regulated by tensiometers

Table 1. Analysis of variance table of F ratio.

Variable Source	Grain yield	Wt. of 1000 grains	No. of grains/ panicle	Panicle length	Straw yield	Tiller count	Floral sterility	Days to maturity	Water requirement	Root length	Root weight	Leaf area
Water regime (W)	6.35**	4.20**	4.91**	2.74**	3.86**	7.20**	3.34**	6.71**	5.35**	2.98**	3.70**	16.4**
Variety (V)	5.04*	27.29**	2.38	13.01**	20.00**	234.80**	2.09	0.25	3.23	19.01**	5.50**	2.8
WXV	1.03	1.34	0.24	1.20	1.24	3.2**	0.55	3.60**	0.76	1.05	0.76	0.62

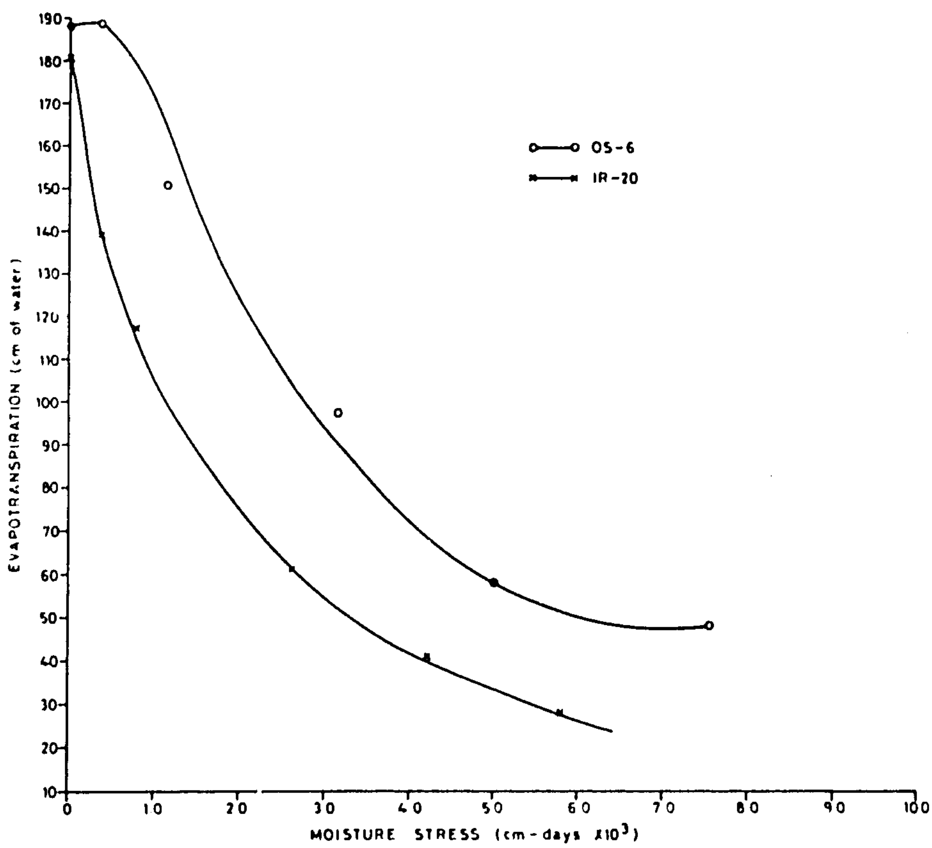

Fig.1. Effects of accumulative soil moisture stress on evapotranspiration.

Table 2. Influence of soil moisture regime on plant height.

Treatment	9/6	16/6	24/6	30/6	7/7	14/7	21/7	28/7	4/8	11/8	18/8
(a) IR20											
Zero suction	31.7	48.0	59.3	74.0	90.0	94.7	99.3	100.0	103.3	103.0	105.0
250 cm suction	31.3	41.7	55.3	64.0	71.0	77.0	77.3	80.7	81.7	85.0	85.0
500 cm suction	35.7	47.3	59.7	63.0	65.7	67.3	69.0	70.7	71.3	72.3	74.3
750 cm suction	34.0	47.0	61.0	63.0	64.5	64.5	64.5	64.5	64.5	68.5	70.0
Submergence 20 DAS	33.3	42.0	55.0	65.7	80.3	92.3	98.0	101.7	103.3	104.0	106.0
Submerg. 35 DAS	32.7	43.0	52.7	61.0	72.7	82.0	82.7	90.3	91.7	94.3	101.7
Submerg. 55 DAS	30.7	39.0	50.0	56.7	63.3	67.0	71.7	86.7	93.0	96.7	98.3
Irrigation at leaf rolling	31.3	36.3	48.7	53.0	57.7	58.0	59.3	61.0	62.7	64.3	64.7
(b) OS6											
Zero suction	51.0	66.7	85.0	97.0	112.3	119.0	130.3	137.0	141.0	148.0	167.3
250cm "	51.0	67.3	86.0	93.7	100.0	118.3	128.3	137.3	143.0	146.7	152.0
500cm "	47.5	65.5	81.0	84.5	96.0	104.0	119.0	119.5	125.0	128.5	134.0
750cm "	54.7	69.0	85.7	90.0	95.7	97.3	102.0	108.7	118.7	126.7	133.3
Submerg. 20 DAS	50.7	66.7	84.7	98.0	117.3	139.3	147.0	153.3	158.7	174.3	204.7
Submerg. 35 DAS	48.0	64.3	80.0	93.0	104.7	123.3	130.0	136.3	145.3	162.3	187.7
Submerg. 55 DAS	54.0	65.7	79.7	90.7	105.3	109.7	124.3	136.7	149.0	157.0	167.0
Irrig. at leaf rolling	51.3	65.0	78.7	81.7	88.7	87.3	102.3	106.0	107.0	108.7	109.0

Table 3. Maximum tiller count and leaf area affected by soil moisture regime.

Soil moisture regime	Tiller count/plant		Leaf area, cm^2/plant	
	IR20	OS6	IR20	OS6
Submergence 20 DAS	28	16	3000	3852
Submergence 35 DAS	30	15	1535	2277
Submergence 55 DAS	28	10	1233	1199
Zero suction	39	16	3137	3648
250 cm suction	29	10	2224	1951
500 cm suction	26	10	1569	1643
750 cm suction	25	10	986	1292
Irrigation at leaf rolling	20	7	972	672
LSD (.05)	6	6	1005	1005

area and tiller count, however, was significantly decreased by soil moisture stress in both varieties.

Dry matter production at various stages of growth. Similar to the field experiments reported in Chapter 3, the highest dry matter production was observed in treatment with submergence from 20 DAS (Table 4, Figs. 2 and 3). It was, however, the treatment with submergence 35 DAS that produced the maximum dry matter from panicle initiation stage onward. There is also a sharp decline in the growth rate for the 500 and 750 cm of water suction treatments even in the initial growth stages. The effect of accumulative moisture stress on dry matter production for zero suction and for the treatments with submergence from 35 and 55 DAS is shown in Figures 2 and 3 for IR20 and OS6, respectively. OS6 has a significantly higher rate of dry matter production than IR20. The effect of delayed submergence such as 35 DAS on enhanced rate of dry matter production is obvious about three weeks after imposing the treatment. Even though there was a significant increase in the rate of dry matter produced for submergence from 35 DAS after the soil was submerged, this rate was significantly lower than that of the other two flooded treatments.

Root development. Whereas the root length of IR20 was significantly decreased by soil moisture stress, that of OS6 was relatively unaffected (Fig. 4).

The sensitivity of root length of IR20 to even a slight drought stress is indicated by the sharp decline in its length as moisture stress increased from 0 to 750 cm-days. The initial decline is then followed by a plateau in the curve up to a soil moisture stress of 6×10^3 cm-days after which there is again a decline in the curve. Drought stress, however, significantly decreased the total root weight for both IR20 and OS6 even in the initial stages of growth (Table 5). The lowest root weight was obtained for the highest degree of soil drought stress such as irrigation at initial leaf curling. For the drought stress levels exceeding that of 250 cm of water suction, OS6 produced about twice as much root mass as IR20. At low stress or with delayed flooding the root weight of OS6 was more by 25-40 percent.

Grain and straw yield. Influence of soil moisture regime on grain yield of IR20 and OS6 is shown in Figure 5 and Table 5. The highest yield, similar to the field experiment reported in Chapter 3, was obtained when submergence was delayed. There was no significant difference in grain yield between the saturated soil with no submergence and the treatment involving submergence from 20 DAS. There occurs a sharp decline in yield as the moisture potential decreases from 0 to 250 cm of water suction. Under the greenhouse conditions, OS6 significantly outyielded IR20 for all the soil moisture regimes investigated. The effect of cumulative soil moisture stress on the grain yield of IR20 and OS6 is shown in Figure 6. There is a definite increase in grain yield with a slight increase in moisture stress, followed by an exponential decrease in yield with increasing soil moisture stress. The maxima in the yield response curve occur at a cumulative moisture stress of about 250 cm-days.

Table 4. Effect of soil moisture regime on dry matter produced (above ground parts only) at various stages of growth (g/plant).

Water regime	29 June 1971		10 July 1971		2 Aug. 1971		30 Aug. 1971		30 Oct. 1971	
	IR20	OS6	IR20	OS6	IR20	OS6	IR20	OS6	IR20	OS6
Zero suction	2.54	5.75	13.52	20.96	38.43	49.36	123.60	136.50	403.90	604.90
250 cm suction	1.96	5.67	13.06	16.86	31.53	40.94	89.00	122.50	176.00	358.60
500 cm suction	1.64	4.31	6.91	11.13	21.08	27.79	58.50	80.50	121.00	271.30
750 cm suction	1.30	3.78	4.77	7.83	8.97	13.68	19.20	31.00	105.70	232.20
Flooding 20 DAS	3.18	6.10	13.17	25.70	45.32	49.70	185.50	197.50	389.00	604.30
Flooding 35 DAS	1.76	3.36	9.07	13.32	44.05	50.57	208.00	228.50	442.40	626.50
Flooding 55 DAS	1.76	1.76	8.29	7.44	37.09	28.01	126.50	128.90	290.00	535.50
Irrigated at wilting	2.60	1.99	5.35	7.13	10.72	12.39	23.00	36.50	88.00	147.10
Mean	2.09	3.71	9.26	12.54	29.65	34.05	91.67	120.11	239.50	422.52
LSD (.05)	1.19		4.34		9.39		51.46		141.18	

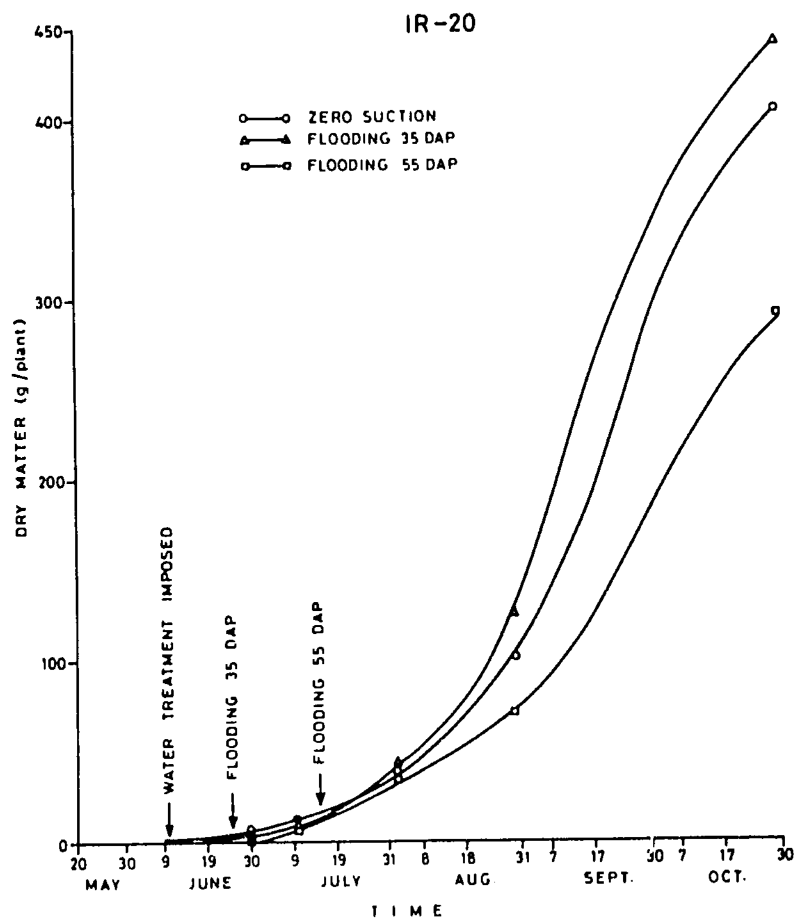

Fig.2. Effect of soil moisture regime on dry matter production in IR-20.

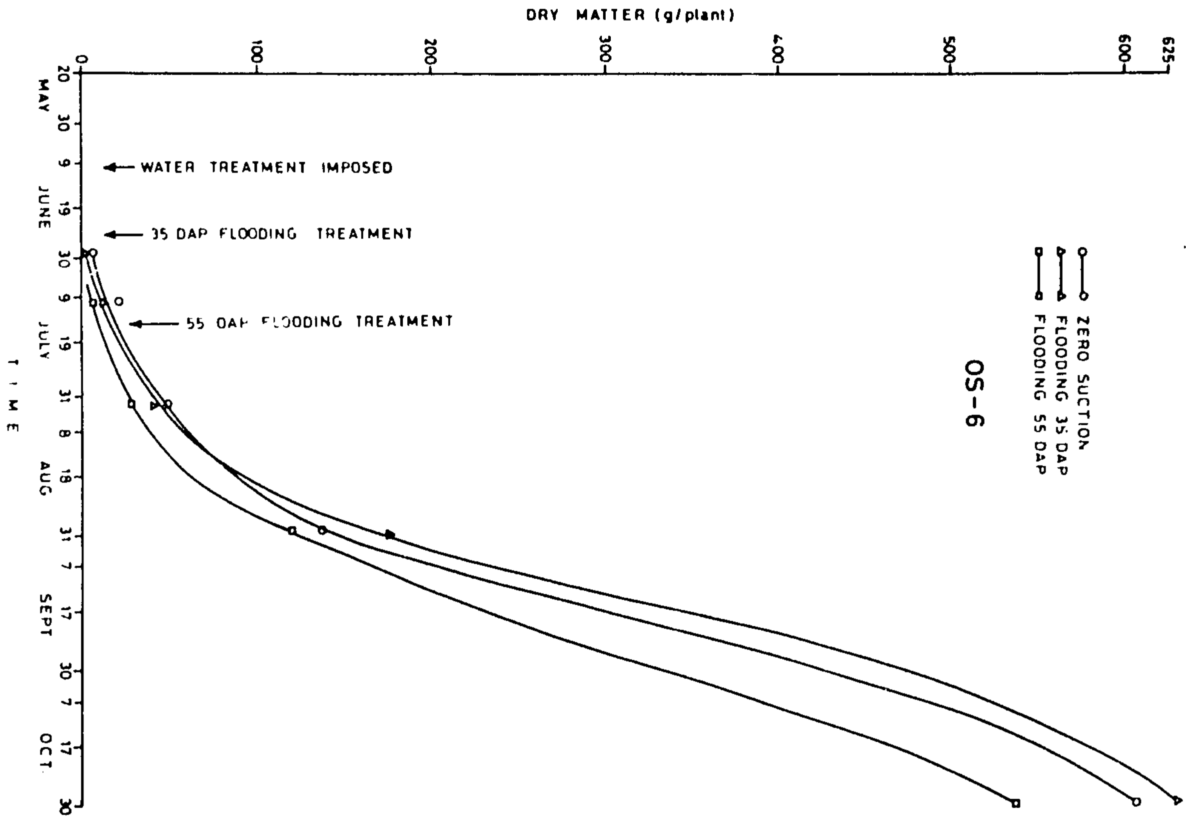

Fig.3. Effect of soil moisture regime on dry matter production in OS-6.

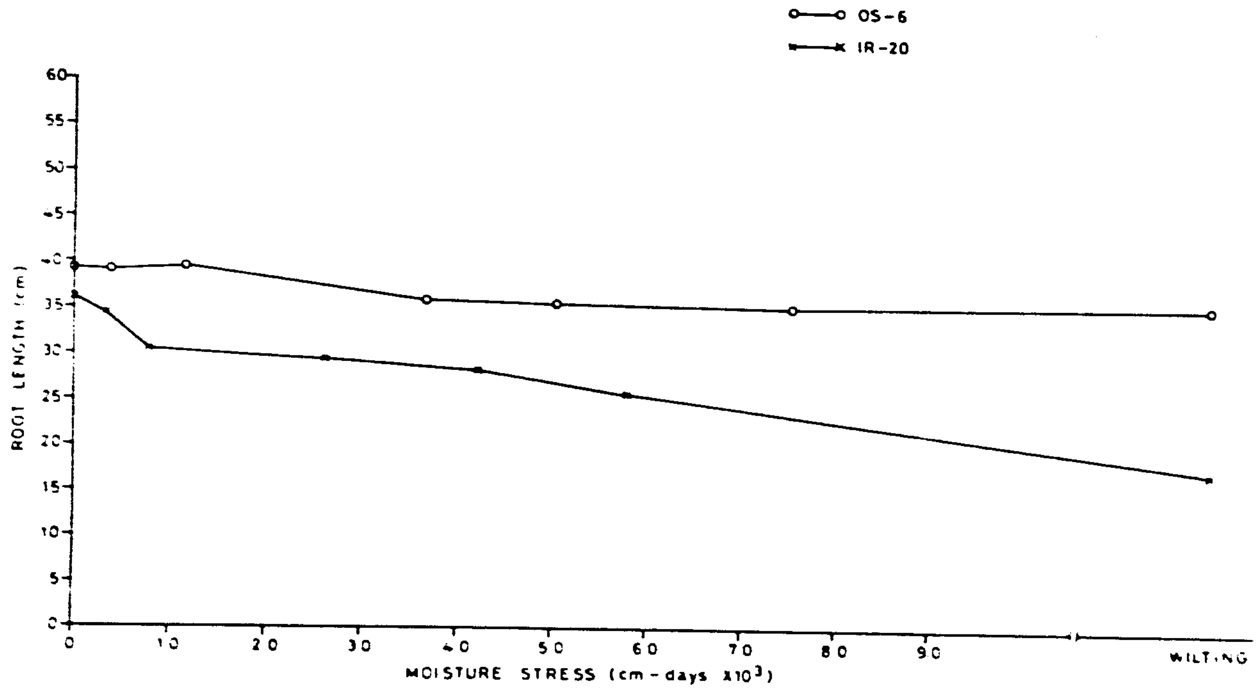

Fig.4. Effect of accumulative soil moisture stress on root length.

Table 5. Influence of soil moisture regimes on grain yield of IR20 and OS6 (Greenhouse, 1971).

Moisture regime	Variety	Grain yield (g/pot)
Submergence 20 DAS	OS6	260.7 a
Zero suction	OS6	248.6 a
Submergence 35 DAS	OS6	223.3 a
Submergence 35 DAS	IR20	209.7 a b c
Submergence 55 DAS	OS6	248.2 a b c
Submergence 20 DAS	IR20	188.0 a b c
Zero suction	IR20	17[illegible].8 a b c d
Submergence 55 DAS	IR20	154.4 a b c d e
250 cm suction	OS6	95.0 b c d e f
250 cm suction	IR20	88.8 c d e f
750 cm suction	OS6	57.6 d e f
500 cm suction	OS6	56.7 d e f
500 cm suction	IR20	26.7 e f
750 cm suction	IR20	24.3 e f
Irrigation at leaf rolling	OS6	19.3 f
Irrigation at leaf rolling	IR20	16.7 f

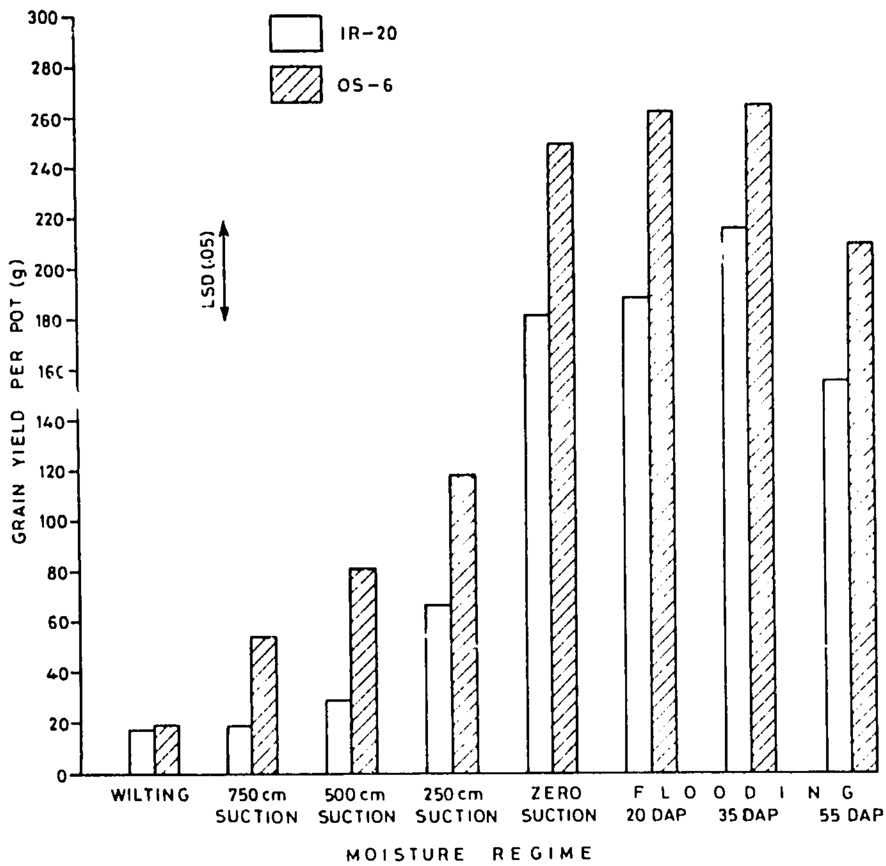

Fig.5. Effect of soil moisture regime on grain yield of IR-20 and OS-6 (DAP means "days after planting").

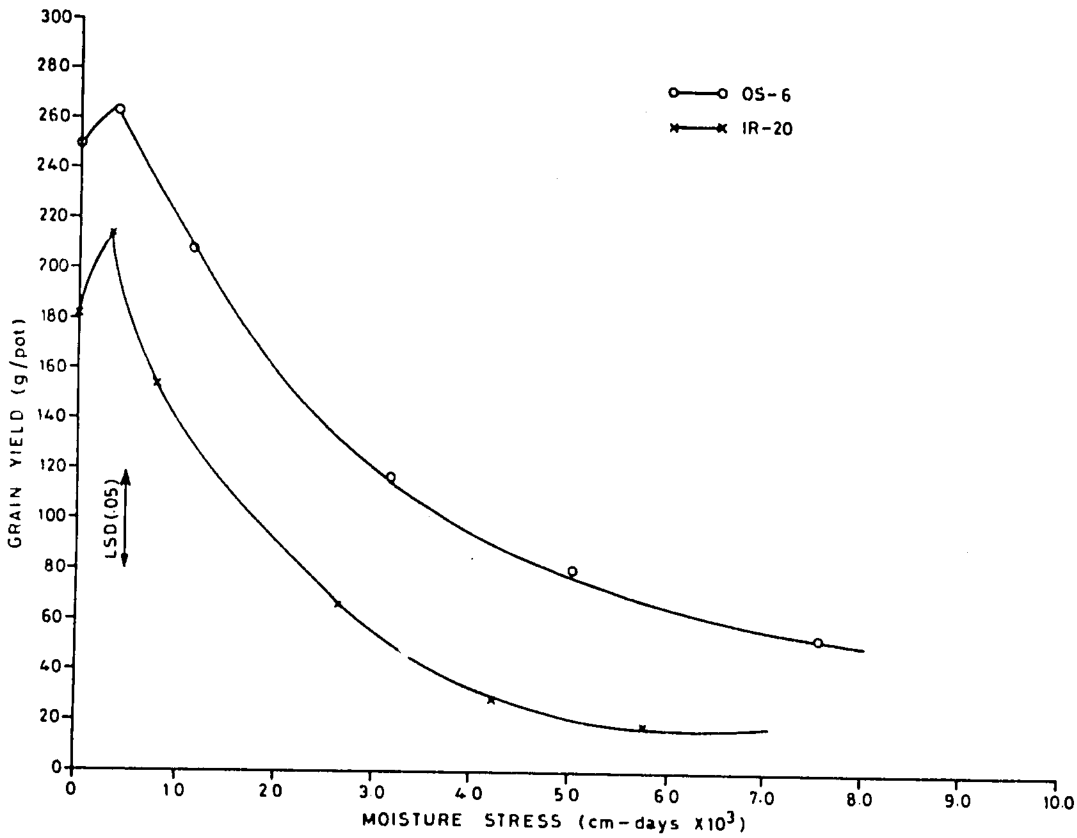

Fig.6. Effect of accumulative moisture stress on grain yield.

The straw yield was affected in a manner similar to that of the grain yield (Fig. 7). The maximum straw yield was obtained for submergence from 35 DAS, though there were no significant differences in straw yield among treatments involving saturated soil and submergence at different growth stages. Straw yield for OS6 was also significantly higher than that of IR20 for all the moisture regimes.

The regression equations of grain yield with other parameters are shown in Tables 6, 7 and 8. The grain yield, as could be expected, is most significantly correlated with total consumptive water use. Grain yield per cm of water use is shown in Table 9.

Nutrient uptake. Leaf and stem samples, collected at the panicle initiation stage and analyzed for P, K, Ca, Mg, Zn, Cu, Fe, and Mn, showed a significant decrease only in P concentration for both varieties. The P concentration decreased from 44 percent to 25 percent for IR20 and from 35 percent to 22 percent for OS6 as the soil moisture stress was increased from soil saturation to wilting. It is possible that N uptake was also affected, but the samples were not analyzed for N content. The leaf and stem concentration of other elements analyzed was not affected by soil moisture regime (Tables 10, 11, 12, 13).

Lodging. There were significant differences in lodging due to both variety and water regime. Generally OS6 lodged more than IR20. Flooded treatments of OS6 lodged earlier than IR20, though both lodged equally at maturity. Treatments with flooding 20 and 35 DAS were given support and there was some lodging for flooding 55 DAS. There was no lodging for the other treatments. High temperatures in the greenhouse probably contributed to premature lodging of both varieties. Lodging was related

Table 6. Regression equations of yield with other parameters. (These equations apply to the combined data of both IR20 and OS6).

Parameter	r	Regression equation
Water use	0.93	y = 1.30 x -13.23
Panicle length	0.83	y = 21.3 x -377.3
Grains per panicle	0.84	y = 1.81 x -70.6
Unit grain weight	0.62	y = 5.89 x +10.33
Straw weight	0.85	y = 0.78 x -26.78

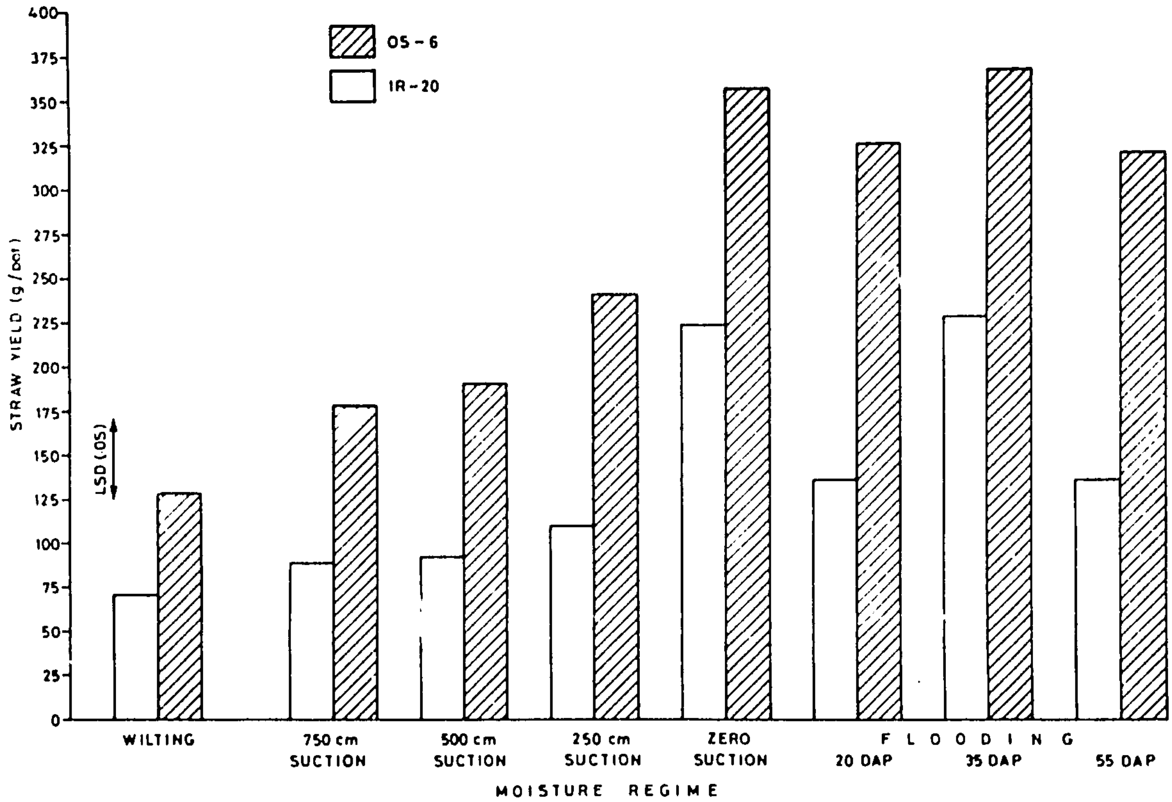

Fig.7. Effect of soil moisture regime on straw yield.

Table 7. Regression equation relating grain yield with other parameters.

Dependent variable	Independent variable	r	Regression equation
Grain yield	Unit grain weight	0.62^{**}	y = 10.33 + 5.89x
"	Panicle length	0.83^{**}	y = 377.3 + 21.36x
"	Grains/panicle	0.84^{**}	y = -70.6 + 1.81x
"	Floral sterility	-0.55^{**}	y = 178.2 - 3.09x
"	Straw yield	0.85^{**}	y = -26.8 + 0.78x
"	Days to maturity	-0.67^{**}	y = 851.8 - 5.3x
"	Root length	0.63^{**}	y = 173.9 + 9.0x
"	Root axis	0.58^{**}	y = -93.7 + 23.9x
"	Root perimeter	0.64^{**}	y = -107.3 + 8.6x
"	Root weight	0.45^{**}	y = 52.4 + 3.1x
"	Shoot length	0.74^{**}	y = -53.1 + 1.39x
"	Live shoot weight	0.87^{**}	y = -20.2 + 0.92x
"	Dead shoot weight	0.40^{*}	Y = 74.8 + 1.39x
"	Leaf area	0.65^{*}	-
"	Tiller	0.099	-

Grain yield (g/pot) = -38.8 + 0.0024 LA - 0.65 T + 1.29 ET

LA = Leaf area cm^2/plant

T = Tiller count/plant

ET = Total water

(R^2 = 0.94)

Table 8. Simple correlation coefficient and regression equations of yield and yield components with water use.

Dependent variable	Independent variable	r	Regression equation
Grain yield	Water use 20-35 days	0.78^{**}	y = 69.7 + 9.5 ET
Grain yield	Water use 20-55 days	0.89^{**}	y = 12.7 + 4.85 ET
Grain yield	Water use 20-70 days	0.90^{**}	y = 6.8 + 3.12 ET
Grain yield	Water use 20-180 days	0.93^{**}	y =-13.2 + 1.3 ET
Floral sterility (%)	Water use 20-35 days	-0.39^{**}	y = 21.4 - 0.85 ET
Floral sterility (%)	Water use 20-55 days	-0.52^{**}	y = 28.2 - 0.51 ET
Floral sterility (%)	Water use 20-70 days	-0.55^{**}	y = 29.5 - 0.34 ET
Floral sterility (%)	Water use 20-180 days	-0.58^{**}	y = 31.7 - 0.14 ET

$$\text{Floral sterility (\%)} = 37.2 + d\ 1.69\,(ET_{20-35}) + 0.75\,(ET_{20-55}) - 1.17\,(ET_{20-70}) - 3.22\,(ET_{20-180}),\ R^2 = 0.65$$

Table 9. Grain yield/cm of water used as influenced by soil moisture regime.

Soil moisture regime	Variety	Grain yield/cm water (g)
Submergence 35 DAS	OS6	1.39
Submergence 55 DAS	OS6	1.38
Zero suction	OS6	1.32
Submergence 20 DAS	OS6	1.29
Submergence 55 DAS	IR20	1.23
250 cm suction	OS6	1.19
Submergence 35 DAS	IR20	1.17
750 cm suction	OS6	1.13
Submergence 20 DAS	IR20	1.13
250 cm suction	IR20	1.09
Zero suction	IR20	1.03
500 cm suction	OS6	0.96
Irrigation at leaf rolling	IR20	0.88
500 cm suction	IR20	0.79
750 cm suction	IR20	0.65
Irrigation at leaf rolling	OS6	0.63
LSD (.05)	0.49	

Table 10. Influence of soil moisture regime on tissue analysis (%) sampled on 2/8/1971.

(a) IR20

	Treat -ment	P		Fe		K		Na		Mg		Ca		Mn		Zn	
		S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L
Submergence	20DAS	0.39	0.29	0.04	0.02	2.77	1.80	0.34	0.17	0.06	0.06	0.09	0.31	0.04	0.02	0.007	0.002
	35DAS	0.41	0.32	0.03	0.01	2.88	3.00	0.50	0.17	0.06	0.06	0.08	0.64	0.02	0.02	0.006	0.002
	55DAS	0.59	0.39	0.02	0.01	2.70	1.65	0.24	0.17	0.06	0.06	0.09	0.27	0.04	0.02	0.008	0.003
Suction	Zero	0.44	0.23	0.02	0.01	2.77	1.52	0.27	0.19	0.06	0.06	0.11	0.25	0.02	0.01	0.006	0.002
	250cm	0.48	0.34	0.02	0.02	2.70	2.20	0.26	0.15	0.06	0.06	0.33	0.02	0.02	0.02	0.008	0.004
	500cm	0.31	0.23	0.01	0.01	2.10	2.10	0.31	0.20	0.06	0.06	0.10	0.33	0.02	0.030	0.010	0.005
	750cm	0.39	0.25	0.02	0.03	2.70	1.35	0.26	0.14	0.06	0.06	0.08	0.21	0.02	0.020	0.010	0.004
	Leaf rolling	0.36	0.49	0.02	0.03	1.75	2.88	0.15	0.19	0.06	0.06	0.08	0.26	0.03	0.03	0.009	0.002

S - stem

L - leaves

Table 11. Influence of soil moisture regime on tissue analysis (%) sampled on 2/8/1971.

(b) OS6

Treat -ment		P		Fe		K		Na		Mg		Ca		Mn		Zn	
		S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L
Submergence	20DAS	0.28	0.31	0.02	0.02	2.00	1.75	0.37	0.22	0.06	0.06	0.04	0.22	0.02	0.02	0.004	0.004
	35DAS	0.44	0.34	0.04	0.02	2.86	2.20	0.57	0.17	0.06	0.06	0.03	0.18	0.04	0.03	0.006	0.003
	55DAS	0.53	0.35	0.02	0.02	2.99	2.40	0.36	0.19	0.06	0.06	0.05	0.23	0.04	0.04	0.010	0.004
Suction	Zero	0.19	0.21	0.02	0.02	2.70	2.00	0.22	0.17	0.06	0.06	0.07	0.37	0.02	0.02	0.008	0.004
	250cm	0.28	0.22	0.01	0.02	3.00	2.20	0.26	0.24	0.06	0.06	0.07	0.27	0.03	0.04	0.009	0.004
	500cm	0.31	0.25	0.01	0.02	2.35	2.25	0.22	0.20	0.06	0.06	0.07	0.31	0.03	0.03	0.008	0.004
	750cm	0.28	0.22	0.01	0.01	2.77	2.00	0.24	0.19	0.06	0.06	0.08	0.23	0.03	0.03	0.009	0.004
Leaf rolling		0.34	0.31	0.03	0.03	2.77	1.70	0.44	0.20	0.06	0.06	0.02	0.23	0.05	0.04	0.008	0.004

S - stem

L - leaves

Table 12. Influence of soil moisture regime on tissue analysis (%) sampled on 30/8/1971. (a) IR20

Treat-ment		P		Fe		K		Na		Mg		Ca		Mn		Zn	
		S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L
Submergence	20DAS	0.49	0.36	0.06	0.04	2.25	2.56	0.68	0.12	0.06	0.06	0.08	0.64	0.03	0.03	0.004	0.003
	35DAS	0.39	0.36	0.03	0.04	1.20	2.00	0.73	0.17	0.06	0.06	0.02	0.47	0.04	0.02	0.002	0.004
	55DAS	0.20	0.32	0.05	0.03	1.80	1.55	0.50	0.17	0.06	0.06	0.15	0.49	0.04	0.02	0.007	0.002
Suction	Zero	0.32	0.32	0.03	0.03	2.40	1.80	0.24	0.14	0.06	0.06	0.13	0.65	0.02	0.06	0.005	0.002
	250cm	0.26	0.23	0.03	0.03	2.56	2.15	0.19	0.17	0.06	0.06	0.15	0.45	0.02	0.02	0.010	0.003
	500cm	0.39	0.32	0.03	0.03	2.56	1.85	0.20	0.14	0.06	0.06	0.16	0.49	0.03	0.03	0.008	0.003
	750cm	0.39	0.32	0.04	0.04	2.15	2.04	0.27	0.19	0.06	0.06	0.20	0.55	0.04	0.06	0.007	0.004
Leaf rolling		0.36	0.47	0.04	0.05	2.56	2.10	0.24	0.14	0.06	0.06	0.18	0.37	0.01	0.03	0.008	0.005

S - stem

L - leaves

Table 13. Influence of soil moisture regime on tissue analysis (%) sampled on 30/8/1971. (b) OS6

	Treat -ment	P		Fe		K		Na		Mg		Ca		Mn		Zn	
		S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L
Submergence	20DAS	0.21	0.25	0.02	0.04	1.12	0.65	0.67	0.27	0.06	0.06	0.02	0.30	0.01	0.03	0.0015	0.002
	35DAS	0.39	0.24	0.02	0.04												
	55DAS	0.36	0.36	0.03	0.04	2.10	1.85	0.52	0.17	0.06	0.06	0.06	0.35	0.03	0.06	0.004	0.004
Suction	Zero	0.26	0.29	0.03	0.04	3.00	2.10	0.20	0.19	0.06	0.06	0.11	0.43	0.05	0.03	0.009	0.005
	250cm	0.21	0.18	0.03	0.03	1.70	1.40	0.17	0.24	0.06	0.06	0.14	0.38	0.02	0.02	0.004	0.004
	500cm	0.22	0.22	0.04	0.04	1.85	2.40	0.17	0.22	0.06	0.06	0.07	0.66	0.05	0.02	0.010	0.003
	750cm	0.28	0.23	0.02	0.04	2.56	2.10	0.20	0.15	0.06	0.06	0.15	0.50	0.03	0.01	0.008	0.004
	Leaf rolling	0.16	0.26	0.03	0.05	1.30	0.45	0.37	0.26	0.06	0.06	0.03	0.32	0.01	0.04	0.002	0.003

S - stem

L - leaves

to root growth, which was different for different varieties and was affected by soil moisture stress. A statistical analysis of various growth parameters is shown in Appendices 6 through 19 and Table 14.

General Conclusions

There is a critical drought stress in terms of both magnitude and duration, beyond which the grain yield declines significantly. This critical level is different for different live varieties and has to be experimentally determined for each genotype. Depending on the soil type, moisture stress of 200 to 250 cm-days or 50 cb and above can seriously reduce grain yield. Some varieties are sensitive to soil moisture stress at any stage of their growth. Therefore, each variety or selection should be evaluated separately for its tolerance to moisture stress. Any generalization in varietal tolerance to moisture stress according to plant type and growth characteristics should be avoided until more is known about physiological characteristics and morphological traits associated with drought tolerance in rice varieties.

Table 14. Effect of soil moisture regime on root weight at various stages of growth (g/plant)

Treatment	2 August 1971		30 August 1971		30 October 1971	
	IR20	OS6	IR20	OS6	IR20	OS6
Zero suction	6.70	7.86	12.50	15.60	31.01	41.50
250 cm suction	5.40	3.72	10.50	12.50	7.75	15.00
500 cm suction	3.54	3.01	10.30	12.00	7.00	13.33
750 cm suction	0.47	0.94	7.00	8.00	6.70	13.31
Submergence 20 DAS	7.04	8.24	11.00	14.60	25.67	45.60
Submergence 35 DAS	8.54	8.76	10.00	12.00	29.60	46.70
Submergence 55 DAS	8.08	7.89	9.00	12.00	22.00	28.30
Cyclic submergence	1.11	0.49	6.00	8.00	5.70	10.40
Mean	5.12	5.11	9.53	11.83	16.80	26.76
L.S.D. (.05)	2.41		1.98		10.65	

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5. EFFECTS OF SOIL MOISTURE STRESS AT DIFFERENT GROWTH STAGES

The physiological effects of soil moisture stress on rice yield are not yet established. Drought stress has been shown to decrease photosynthesis and respiration and increase the ratio of respiration to photosynthesis. Decrease in photosynthesis is attributed primarily to closure of the stoma during water stress. Ralley and Adair (1943) observed that rice grown under continually submerged conditions was vigorous with more tillers, and produced more grain and straw yield than that grown under drought stress. Senewiratne and Mikkelsen (1961) reported from studies conducted in California that grain yield was 53 percent lower under non-flooded compared with unstressed conditions. Tissue dehydration has been reported to be the cause of decreased vigor and growth (Jana and Ghildyal, 1967).

The concept of "critical" stage of growth has been put forward by many authors (Salter and Goode, 1967; Chang, 1968). It is believed that the effects of moisture stress are more pronounced at some growth stages than others. Salter and Goode (1967) and Slatyer (1969) concluded that cereals are more sensitive to moisture stress at flowering, and can recover from mild or relatively brief periods of moisture stress if favourable conditions can be quickly restored. Matushima (1962) found that rice is most sensitive to water stress from 20 days before to 10 days after heading.

Knowing critical stage of crop growth can help plan management operations to avoid or minimize the stress. However, greater attention should be directed to plant's response after the plant has undergone stress (Laude, 1971).

The influence of soil moisture stress on IR-20 was investigated at IITA from November 1971 to March 1972 using field lysimeters. The treatments consisted of (i) submergence 20 days after seeding (DAS) and a suction of 100 cm before, (ii) submergence 35 DAS, (iii) submergence 55 DAS, (iv) zero suction at 15 cm depth, (v) 50 cm suction at 15 cm depth, and (vi) 100 cm suction at 15 cm depth. Methodology is shown in Appendix 5, and the results are presented below:

<u>Plant height</u>. Since the moisture treatments were imposed 20 DAS, there were no significant differences in plant height until 50 DAS (Table 1). Thenceforth, plant height followed a trend depending on soil moisture regimes. In general, the submerged plants had vigorous vegetative growth and more height than the unsubmerged plants. This trend in plant height was consistent throughout the growth period. At maturity, there were no significant differences in plant height amongst 3 submerged treatments. Similarly, the plant height of the unsubmerged treatments was not different

Table 1. Influence of soil moisture stress on height /1 (cm) at different growth stages (November 1971 - March 1972).

Treatment	Plant height at different growth stages (DAS)										
	24	31	39	46	53	60	67	74	81	88	Final height
Submergence 20 DAS	34	49	51	53	61	66	72	82	91	104	97
Submergence 35 DAS	32	42	43	46	56	63	68	83	94	101	95
Submergence 55 DAS	33	43	44	44	46	54	68	85	88	97	97
Zero suction at 15 cm	33	43	44	46	47	55	63	71	76	81	84
50 cm suction at 15 cm	34	42	43	44	46	50	58	66	71	82	85
100 cm suction at 15 cm	30	42	43	43	46	52	55	66	69	76	81
LSD (.05)	4.6	8.0	7.4	7.2	6.3	9.1	9.5	10.6	11.8	8.6	7.2
"F" ratio	0.8	1.2	1.8	2.3	7.7**	4.4*	4.2*	6.1**	7.5**	17.2**	9.1**

/1 Each figure is an average of 12 plants per treatment.

Table 2. Dry matter produced (g/plant) at different growth stages.

Treatment	Dry matter at different days after planting				
	20	35	55	70	90
Submergence 20 DAS	0.44	1.80	8.16	10.08	13.28
Submergence 35 DAS	0.64	1.52	9.20	10.24	21.68
Submergence 55 DAS	0.52	1.08	6.76	8.56	12.40
Zero suction	0.36	1.52	6.92	8.12	16.00
50-cm suction	0.48	1.28	6.96	8.68	12.16
100-cm suction	0.48	0.88	5.96	7.32	11.00
LSD (.05)	0.08	0.92	1.68	2.52	8.20
"F" ratio	1.60	1.74	4.15*	1.72	2.00

from one another, though the least height was measured for the plants subjected to the highest level of soil moisture stress. There were significant differences in plant height of the submerged plants from those of the unsubmerged one, the former being taller by 10 to 15 cm compared with the latter. The plants under submerged conditions are taller perhaps because of the longer culm length.

Tiller count. Although the plant height was significantly affected by moisture stress, the tillering behavior was not. The numbers of tillers/m^2 were not statistically different amongst various moisture regimes at any stage of crop growth. In fact, an analysis of the data reveals that the stressed treatments had consistently more tiller count than the submerged lysimeters (Table 2). Lower tiller count per unit area was observed for the treatment with submergence from 20 DAS. Similar results have been reported by other workers (Cralley and Adair, 1943; Yamada and Ota, 1957; Maurya and Ghildyal, 1975). Even though the number of tillers is larger with a slight stress, the number of actually productive tillers may be less. Most of the tillers produced under adequate soil moisture levels are productive, whereas several tillers in stressed conditions are barren. Similar results have been reported by Have (1959), Chaudhry and McLean (1963).

Dry matter production. Changes in the dry weight of shoot at different growth stages as affected by soil moisture regime are shown in Table 3. Dry matter was generally lower for the unsubmerged compared with the submerged treatments as from about 35 DAS. The dry matter production of shoots progressively increased with the decrease in moisture suction and with earlier submergence.

The decrease at 90 DAS in the stressed treatments was 24 and 31 percent respectively for 50 cm and 100 cm of water suction compared with that of zero-suction treatment. The dry matter production with zero-suction treatment at 90 DAS was more than that of continuous submergence from 20 DAS.

Yield and yield components. Grain yield and yield components affected by soil moisture regime are shown in Table 4. Although yield declined with increase in moisture stress, and with longer delay in submergence, the total yield was not statistically significant amongst various moisture regimes. Grain yield was suppressed by 3.6 and 13.4 percent respectively in 50 cm and 100 cm of water suction compared with zero suction treatment. Similarly the relative decrease in yield as compared with submergence from 20 DAS was only 4.2, 5.7, and 12.6 percent respectively for zero suction, submergence 35 DAS, and submergence 55 DAS. If the moisture suction prior to submergence was kept near zero (saturated soil), treatments with submergence 35 and 55 DAS may have

Table 3. Influence of soil moisture regime on tiller count (number/m^2) at different growth stages (November 1971 - March 1972).

Treatment	Tiller count at different growth stages (DAS)									
	25	32	40	47	54	61	68	75	82	89
Submergence 20 DAS	1433	1750	1883	1940	2250	2320	2373	2397	2417	2443
Submergence 35 DAS	1786	1987	2053	2103	2257	2333	2397	2397	2440	2490
Submergence 55 DAS	2270	2417	2583	2580	2743	2953	3010	3017	3037	3040
Zero suction at 15 cm	1880	2320	2420	2497	2737	2933	2963	2980	2987	2990
50-cm suction	1870	2127	2200	2310	2783	2957	2980	2997	3000	2993
100-cm suction	1700	2357	2380	2540	2820	2903	2953	2963	2953	2950
LSD (.05)	217	485	612	630	675	822	865	822	820	781
"F" ratio	1.44	1.27	1.54	1.55	1.47	1.78	1.21	1.23	1.11	1.06

Table 4. Influence of soil moisture regime on grain yield and yield components. (November 1971 - March 1972).

Treatment	Grain yield T/Ha	Panicle length (cm)	Number of grains per panicles	Empty grains (%)	Weight of 1000 grains (g)	Empty grains per panicle. (%)
Submergence 20 DAS	5.32	22.62	149	9.32	16.40	14
Submergence 35 DAS	5.02	22.31	144	9.35	15.83	12
Submergence 55 DAS	4.65	22.94	146	12.68	14.07	18
Zero suction	5.10	22.42	131	11.71	15.97	16
50-cm suction	4.92	24.28	137	8.78	16.20	12
100-cm suction	4.42	22.21	113	9.45	16.70	11
LSD (.05)	0.87	n.s	33	4.26	1.52	6
"F" ratio	1.23	n.s	1.43	1.22	3.36*	1.63

outyielded the one with submergence from 20 DAS (See Chapter 4). It is interesting to observe that soil moisture regime treatments imposed did not significantly influence grain yield in this experiment.

Panicle length and floral sterility were also significantly different amongst various treatments investigated. The yield differences amongst various treatments are attributed to differences in the number of full grains per panicle. The maximum number of grains per panicle was obtained in the treatment with submergence from 20 DAS, and the lowest in case of stressed treatment with 100 cm of moisture suction maintained at 15-cm depth. The unit grain weight was not affected by soil moisture treatments.

Consumptive water use. The influence of soil moisture regime on consumptive water use (or more appropriately, the amount of water required to maintain the desired soil moisture regime) was significantly influenced by moisture treatments imposed. In general, the highest amount of water consumed was recorded for the submerged treatment. The earlier the submergence imposed, the more was the water requirement (Table 5). The least amount of water was used in three stressed treatments. Similar results have been reported by Ghildyal (1971).

The moisture suction records were obtained in the stressed lysimeters. The low-lying paddy remained at 100 to 150 cm of water suction throughout the growing period. It is apparent that economical level of rice yield can be obtained from the valley bottom soil without supplemental irrigation even during the dry season (Moormann, 1975).

Water use efficiency. Water use efficiency of rice, expressed as kg of grains/ha/mm of water added, as influenced by soil moisture regimes is shown in Table 6. Water use efficiency was the highest in case of stressed treatments and the lowest under submerged conditions.

However, if similar experiments were conducted under upland soils, the results would have been different. These results support the findings of Moormann and colleagues, and strengthen the belief that in West Africa valley bottom soils should be developed for rice production.

Table 5. Amount of water added/lysimeter to maintain the desired moisture regime at various growth stages (cm).

Treatment	70 DAS	90 DAS	Maturity
Submergence 20 DAS	22.3	33.1	52.2
Submergence 35 DAS	16.5	32.0	51.1
Submergence 55 DAS	10.6	26.8	47.5
Zero suction	9.0	18.7	32.6
50-cm suction	7.2	15.6	29.9
100-cm suction	0.1	2.6	6.8
LSD (.05)	6.55	9.28	13.04
"F" ratio	11.80**	13.40**	18.40**

DAS = Days After Seeding

Table 6. Water use efficiency as influenced by soil moisture regime (kg grain/Ha/mm of water added).

Treatment	Water use efficiency
Submergence 20 DAS	10.2
Submergence 35 DAS	9.8
Submergence 55 DAS	9.9
Zero suction	19.6
50-cm suction	18.6
100-cm suction	71.9
LSD (.05)	13.1*
"F" ratio	13.1*

General conclusions.

1. There are significant varietal differences toward response of moisture stress to grain yield at different stages of growth.

2. The results obtained at IITA indicate that rice production in valley bottom soils, conditions similar to those of the experimental sites, can be economical even without supplementary irrigation but with adequate water control.

3. If during the initial stages the soil moisture stress is not severe, it may have some beneficial effects. The plants have a "hardening" effect if a slight drought stress occurs in the initial periods of crop growth. For example, field studies at IITA indicated no significant differences in grain yield amongst treatments that involved continuous submergence from 20 DAS or submergence from 55 DAS.

4. The critical soil moisture stress beyond which the yield of rice declines is a varietal characteristic, and needs to be investigated in detail.

5. The consumptive water use is affected by the water management system adopted.

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6. CRITICAL SOIL MOISTURE STRESS

Review presented in Chapter 5 indicated that for most varieties, drought stress at any growth stage can adversely affect rice growth and yield. But a low level of soil moisture stress imposed in the initial growth stages can also have some beneficial effects. It implies therefore, that there may be a "critical soil moisture potential" for optimum rice growth. If the soil moisture stress exceeds this critical range, then yield can be significantly reduced. This critical range of soil moisture potential may be rather narrow and variety specific. This concept of delineating the range of "critical soil moisture potential" may be an important aspect in developing varietal screening technique for drought tolerance.

Sen and Gupta (1970) reported optimum yield when soil was kept saturated until pre-tillering stage and then followed by shallow submergence at tillering and re-saturation but no submergence at flowering. Place et al (1971) found that submergence from 12 days after emergence was necessary for sustained high yields. Jana and Ghildyal (1971, 1972) observed that flooding throughout the growth was not necessary for high yields, particularly when evaporative demand was low. Singh and Tomar (1971) reported high yields with submergence until panicle emergence. Similar results have been reported by Bhatia and Dastane (1971) and Vamadevan and Dastane (1972). However, Lin and Wu (1973) obtained highest yield by continuing irrigation throughout panicle initiation stage. In a separate investigation reported by Vamadevan and Dastane (1973), withholding water for a 20-day period 90 days after planting had no adverse effects on rice yield. However, withholding water at tiller initiation stage and at the spikelet primordia differentiation and flowering stage reduced yield from 21 to 27 percent. Lenka et al (1973) reported that intermittent irrigation to maintain the moisture content of the soil between saturation and field capacity from transplanting to peak tillering, followed by a 3-5-cm submergence until ripening produced higher yields than continuous submergence of 3 to 5 cm. But intermittent irrigation from peak tillering to flowering resulted in significant yield reductions. Similar results have been reported by Kaliappa et al (1974) and Singh and Misra (1974). Recent review on water management in rice in India has indicated that a shallow depth of about 5-cm submergence is essential for optimum rice yield (Pande, 1976).

Analysis of the literature reviewed above indicates that high yields are obtainable if plants are kept at near saturation level until floral or panicle initiation stage followed by submergence through floral development and grain filling period. Submergence is not necessary from that stage onward.

Leaf area of plant is also influenced by soil moisture regime, which, in turn, alters the consumptive water use. Total leaf area, arrangement and orientation of leaves and stomatal characteristics are important factors.

A series of greenhouse studies were conducted at IITA, Ibadan, to investigate:

(i) The influence of low level of soil moisture stress on growth, development and yield of rice. This was done to determine threshold of soil moisture potential at which yield declines significantly as compared with continuous saturation.

(ii) The influence of flooding at various stages of growth on rice growth and yield.

Soil moisture treatments consisted of: (i) submergence 20 DAS, 100 cm suction at 15-cm depth before, (ii) zero suction at 15-cm depth, (iii) 25-cm suction at 15-cm depth, (iv) 50-cm suction at 15-cm depth (v) 100-cm suction at 15-cm depth (vi) submergence from 20-55 DAS, 100-cm suction at 15-cm depth before and after, (vii) submergence from 20-70 DAS, 100-cm suction at 15-cm depth before and after, (viii) submergence for 20-90 DAS, 100-cm suction at 15-cm depth before and after. The soil used was the same as the one described in Chapter 4. Some of methodology is shown in Appendix 6.

<u>Plant height</u>. Influence of soil moisture regime on plant height at various growth stages is shown in Tables 1a and 1b. There are significant differences in plant height of IR-20 (Table 1a) at different growth stages under various moisture regimes. Although the plant height of the continuous submergence treatment was the maximum, it was only slightly more than that of the plants with delayed submergence. There were no differences in plant height of treatment with zero suction and that of submergence treatments deferred for various time intervals. Saturated soil with no submergence suppressed plant height only slightly compared with 20 DAS submergence treatment. Moisture suction of only 50 and 100 cm decreased height compared with zero suction treatment (Table 1a).

There are significant varietal differences in plant height as well. Mean plant height of OS-6 was greater than IR-20 for all the soil moisture regimes investigated. Moreover, there are no significant differences in plant height of OS-6 amongst various soil moisture regimes. The final plant height of all the submerged treatments, regardless of the submergence time, was identical. Even the soil moisture suction of 50 and 100 cm of water suction did not significantly suppress final height measurement of the OS-6.

Table 1a. Plant height (cm) of IR-20 at different growth stages (DAS).

Soil moisture regime	Days after seeding								
	20	27	34	41	48	55	62	69	76
Submergence 20 DAS	28.7	48.7	63.7	77.3	89.0	101.7	107.0	113.0	116.7
Zero suction	29.3	42.0	52.0	68.7	79.0	86.7	91.0	93.0	94.0
25-cm suction	27.0	38.0	51.0	62.7	75.3	85.3	92.0	94.3	96.0
50-cm suction	26.0	36.3	43.7	55.7	65.3	73.0	82.7	87.0	86.7
100-cm suction	25.7	36.7	43.0	51.0	61.0	70.0	77.3	79.3	79.3
Submergence 20-55 DAS	27.3	43.7	54.3	64.7	72.7	80.7	85.0	86.3	87.0
Submergence 20-70 DAS	27.0	43.3	56.0	68.3	78.0	89.0	95.0	97.0	97.7
Submergence 20-90 DAS	27.0	43.7	55.3	65.7	73.7	85.3	92.7	95.7	97.0

Table 1b. Plant height (cm) of OS-6 at different growth stages (DAS).

Soil moisture regime	Days after seeding								
	20	27	34	41	48	55	62	69	76
Submergence 20 DAS	34.0	57.3	79.0	93.7	106.3	122.7	134.7	145.0	149.3
Zero suction	35.0	52.7	72.7	90.0	109.3	126.0	136.7	144.3	149.3
25-cm suction	35.7	49.7	74.3	92.3	110.7	126.3	135.3	144.7	149.7
50-cm suction	38.0	58.7	75.0	93.0	110.0	127.3	140.3	145.7	149.7
100-cm suction	34.0	49.7	62.7	76.7	94.7	116.0	130.7	136.0	138.7
Submergence 20-55 DAS	29.5	59.0	78.0	93.0	105.5	118.0	130.0	138.5	142.5
Submergence 20-70 DAS	36.7	54.7	82.3	95.3	110.0	129.3	142.0	147.7	151.0
Submergence 20-90 DAS	36.3	59.0	75.0	85.7	112.3	128.7	141.0	145.7	152.7

Table 2a. Tillering characteristics (number/plant) of IR-20 at different growth stages (DAS).

Soil moisture regime	Days after seeding								
	20	27	34	41	48	55	62	69	76
Submergence 20 DAS	2	3	6	11	16	19	20	21	21
Zero suction	3	4	8	14	20	24	25	27	27
25-cm suction	3	4	8	14	20	26	29	30	30
50-cm suction	3	4	7	12	18	21	24	24	24
100-cm suction	3	4	8	12	18	21	23	24	26
Submergence 20-55 DAS	2	3	5	10	15	18	19	20	20
Submergence 20-70 DAS	3	3	6	10	18	21	22	23	22
Submergence 20-90 DAS	2	3	6	10	15	18	21	21	21

Table 2b. Tillering characteristics (number/plant) of OS-6 at different growth stages (DAS).

Soil moisture regime	Days after seeding								
	20	27	34	41	48	55	62	69	76
Submergence 20 DAS	1	2	4	8	11	12	12	12	12
Zero suction	1	3	4	8	9	10	10	10	10
25-cm suction	1	3	4	6	9	10	11	11	11
50-cm suction	1	3	4	7	10	10	11	11	11
100-cm suction	2	2	4	6	8	8	10	9	9
Submergence 20-55 DAS	1	2	4	7	11	12	12	12	12
Submergence 20-70 DAS	2	2	4	7	12	13	13	13	13
Submergence 20-90 DAS	2	2	5	8	12	13	13	13	13

Tiller count. The influence of soil moisture regime on the tillering behavior of IR-20 and OS-6 for different growth stages is shown in Table 2a and 2b, respectively.

The final tiller count of IR-20 showed significant differences due to the nature of the moisture regimes. Unlike plant height, non-submergence and soil moisture suction increased the tiller count. The lowest tiller count (average 21/plant) was observed in the submerged treatments. There were no differences in the tiller count due to the time of submergence. The tiller count per plant was the highest in the 25-cm suction treatment. Similar trends in tiller count were established from 40 DAS.

The influence of soil moisture regime in the tiller production in OS-6 differed significantly from that of IR-20. Although there were no significant differences among various treatments. Tiller count was the least in 100-cm suction treatment. The influence of moisture regime on plant height and on tiller count of OS-6 is, therefore, quite different.

Leaf area index (LAI). Mean LAI of IR-20 and OS-6 at different growth stages and for different soil moisture regimes is shown in Tables 3 and 4, respectively. The comparison in the LAI of two varieties under different soil moisture regimes is shown in Figures 1 to 8.

Soil moisture regime had significant effect on the LAI. The LAI of IR-20 decreased with increase in soil moisture suction from 25 to 100 cm of water suction. However, there was an increase in the LAI as the suction increased from zero to 25 cm. There were no differences in the LAI among various submergence treatments, and the zero suction treatment.

There were no significant differences in the LAI of OS-6 and IR-20. The influence of moisture regime on the LAI of OS-6 was also similar to that of IR-20. The LAI of OS-6 increased as the suction increased from zero to 25 cm and then decreased significantly with increase in soil moisture suction from zero to 100 cm. Treatment with submergence from 20 to 90 DAS also resulted in higher LAI at 90 DAS.

Submergence at different growth stages also had effect on the LAI. In general, zero suction and submergence at 20 DAS, submergence from 20-90 DAS, and a slight drought stress of 25 cm had similar LAI. For treatment with submergence from 20-55 DAS, IR-20 had significantly lower LAI than OS-6.

Table 3. Mean LAI of IR-20 at different growth stages.

Treatment	Days after planting						
	48	55	62	69	76	83	90
Submergence 20 DAS	6.70	8.93	13.43	18.02	21.32	24.04	26.69
Zero suction	8.45	13.39	15.65	18.78	21.66	23.93	25.33
25-cm suction	5.78	9.65	12.43	17.87	22.17	26.46	28.72
50-cm suction	4.44	8.79	10.67	13.11	15.17	18.73	20.30
100-cm suction	4.57	6.27	8.20	9.45	12.32	14.98	16.72
Submergence 20-55 DAS	4.78	9.29	10.86	14.00	16.35	19.25	20.77
Submergence 20-70 DAS	7.15	11.44	15.33	17.85	21.38	24.69	26.58
Submergence 20-90 DAS	5.96	8.76	12.75	16.14	19.94	22.83	26.81

Table 4. Mean LAI of OS-6 at different growth stages.

Treatment	Days after planting						
	48	55	62	69	76	83	90
Submergence 20 DAS	8.75	10.22	14.54	18.91	21.86	25.34	27.43
Zero suction	9.23	14.79	16.29	19.42	22.08	24.98	25.90
25-cm suction	5.58	7.39	9.64	14.22	19.99	23.89	29.82
50-cm suction	8.23	10.55	12.00	15.36	18.99	20.55	22.76
100-cm suction	3.68	6.27	8.03	10.74	13.06	16.51	18.46
Submergence 20-55 DAS	6.83	10.00	13.98	16.86	20.47	23.24	24.55
Submergence 20-70 DAS	9.29	13.79	18.29	19.80	22.71	23.67	25.73
Submergence 20-90 DAS	10.05	15.67	20.56	23.19	25.89	26.93	29.27

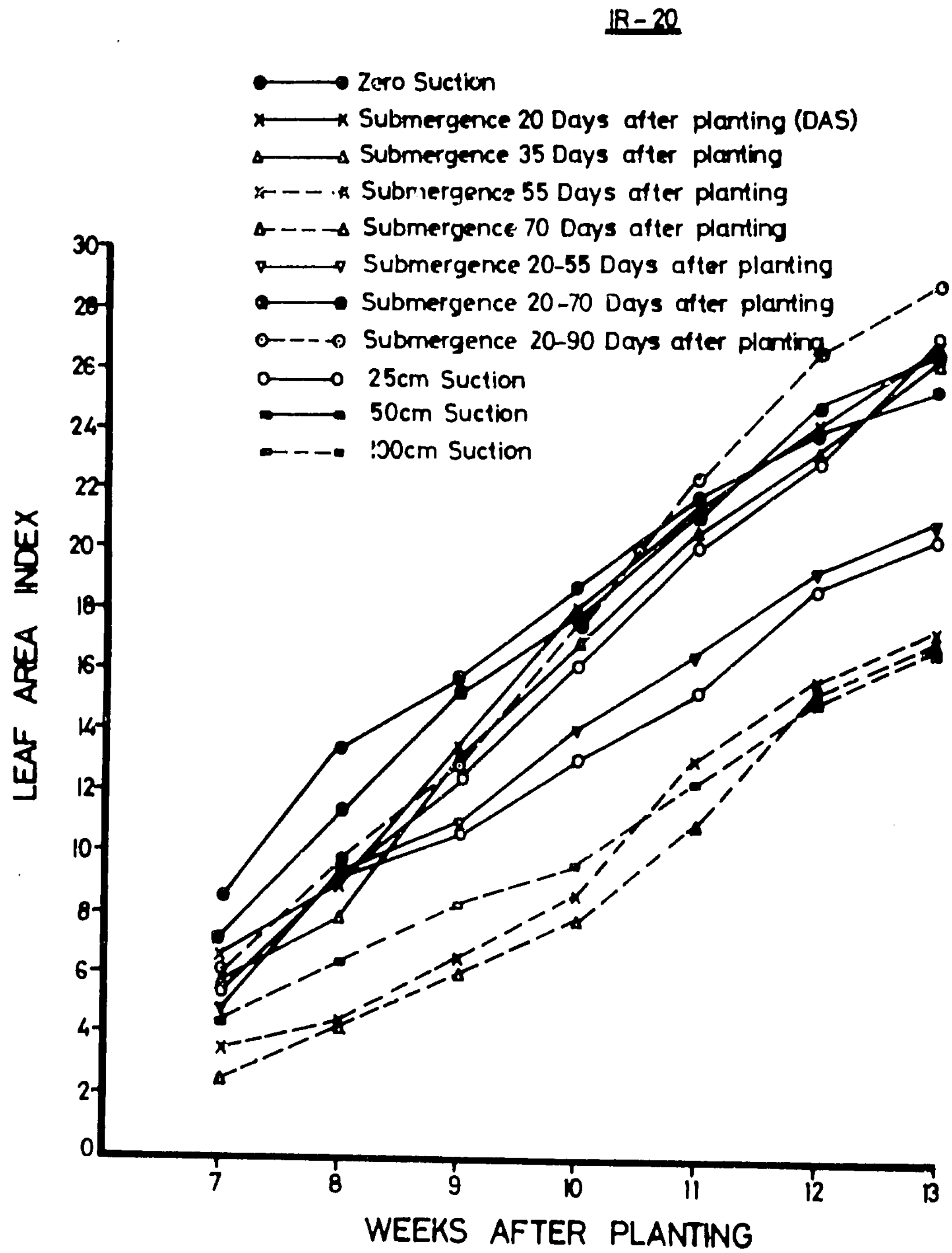

Fig.1. Effects of different soil moisture regimes on the leaf area index of IR-20 at different growth stages.

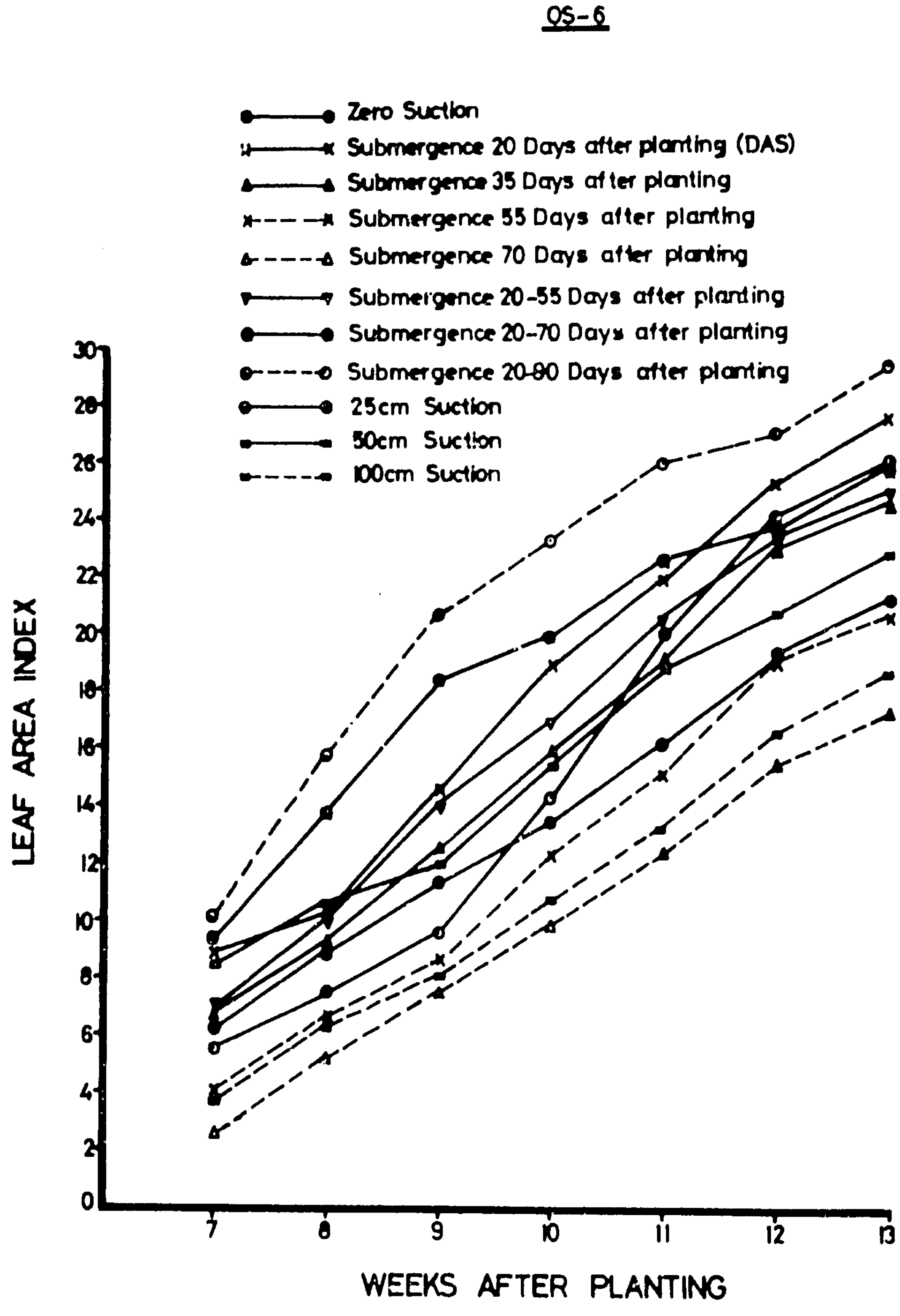

Fig.2. Effects of different soil moisture regimes on the leaf area index of OS-6 at different growth stages.

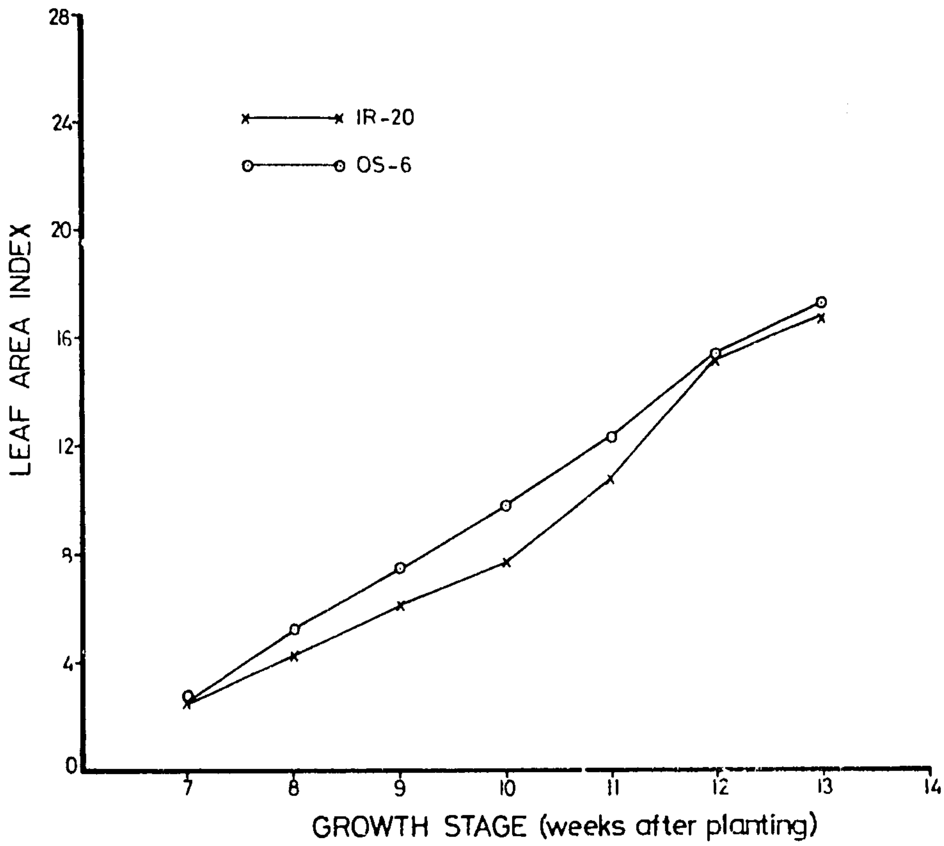

Fig.3. Comparison of the leaf area index of IR-20 and OS-6 for the same moisture regime (continuous submergence from 20 DAS) for different growth stages.

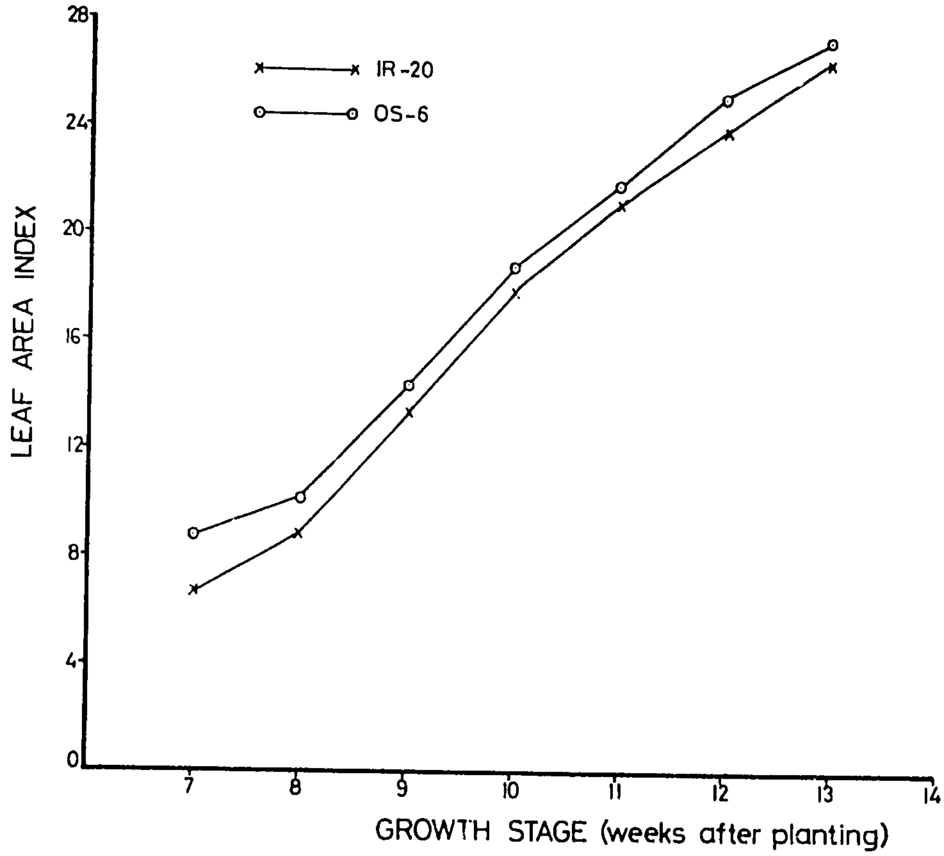

Fig.4. Comparison of the leaf area index of IR-20 and OS-6 for flooding from 70 DAS moisture regime.

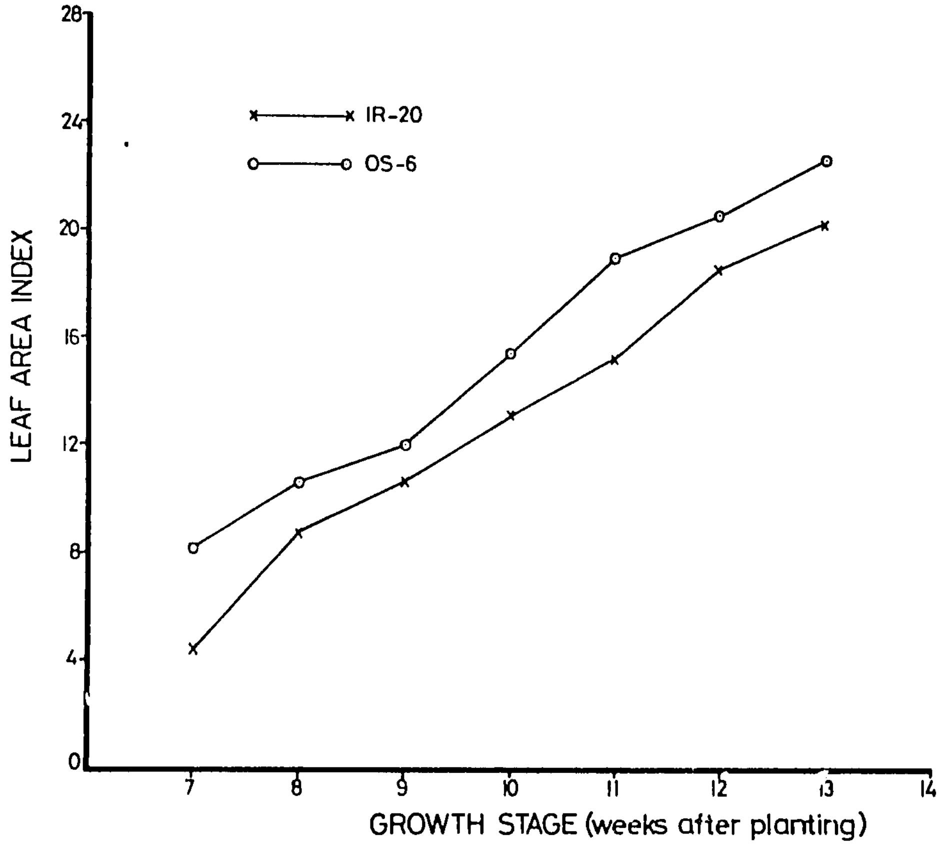

Fig.5. Comparison of the leaf area index of IR-20 and OS-6 for 50 cm water suction at 15 cm depth.

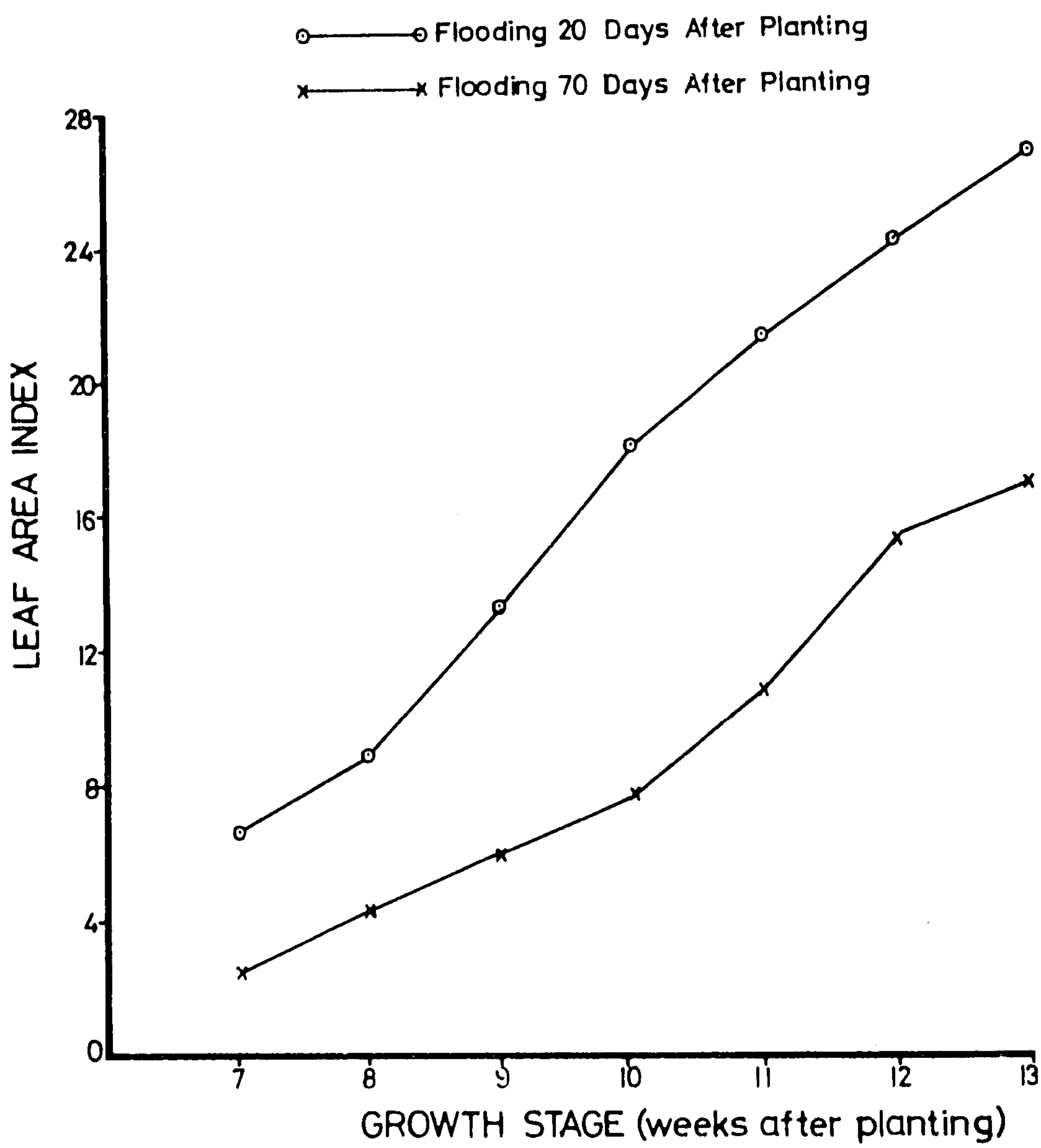

Fig.6. Comparison of the leaf area index of IR-20 for two soil moisture regime i.e. submergence 20 and 70 DAS.

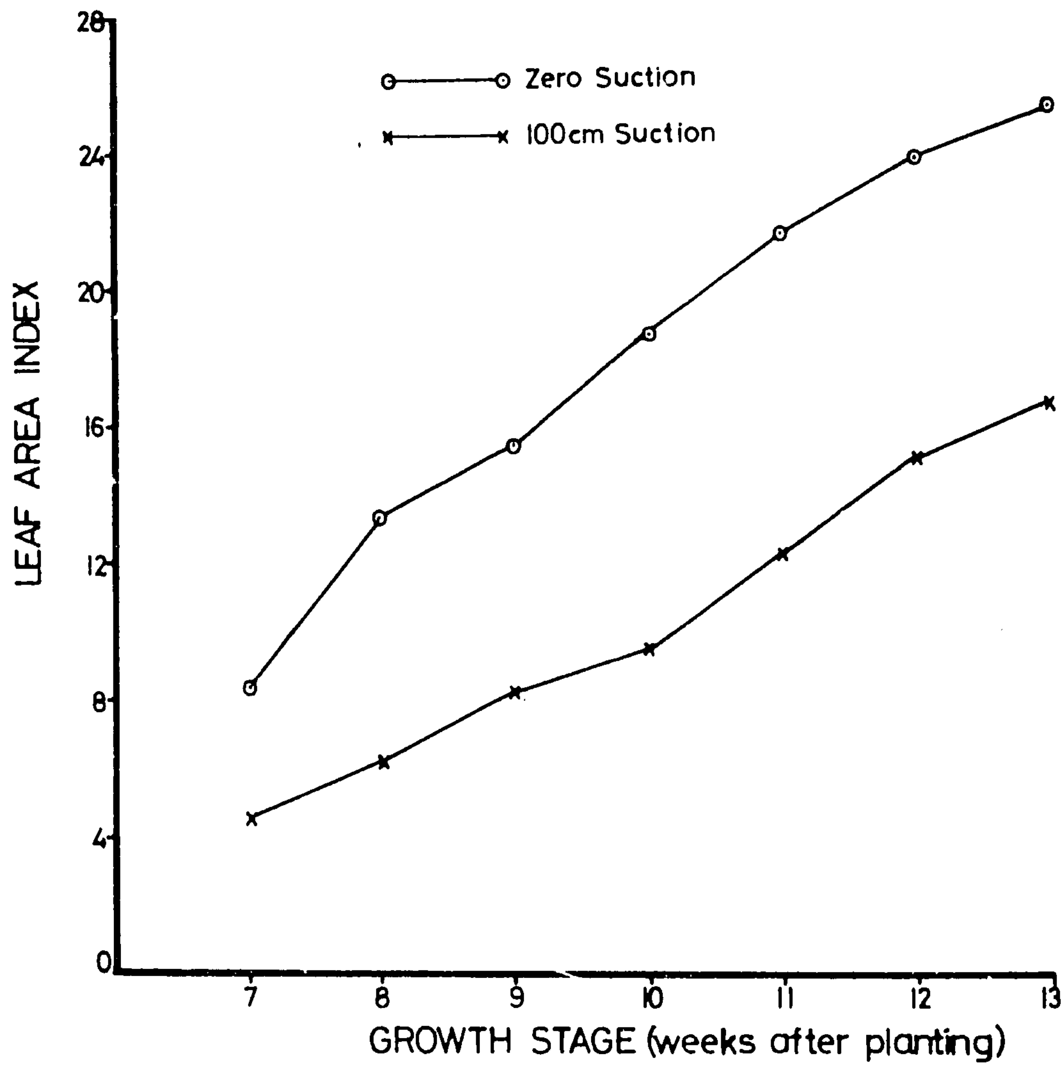

Fig.7. Leaf area index of IR-20 for 0 and 100 cm suction soil moisture regimes.

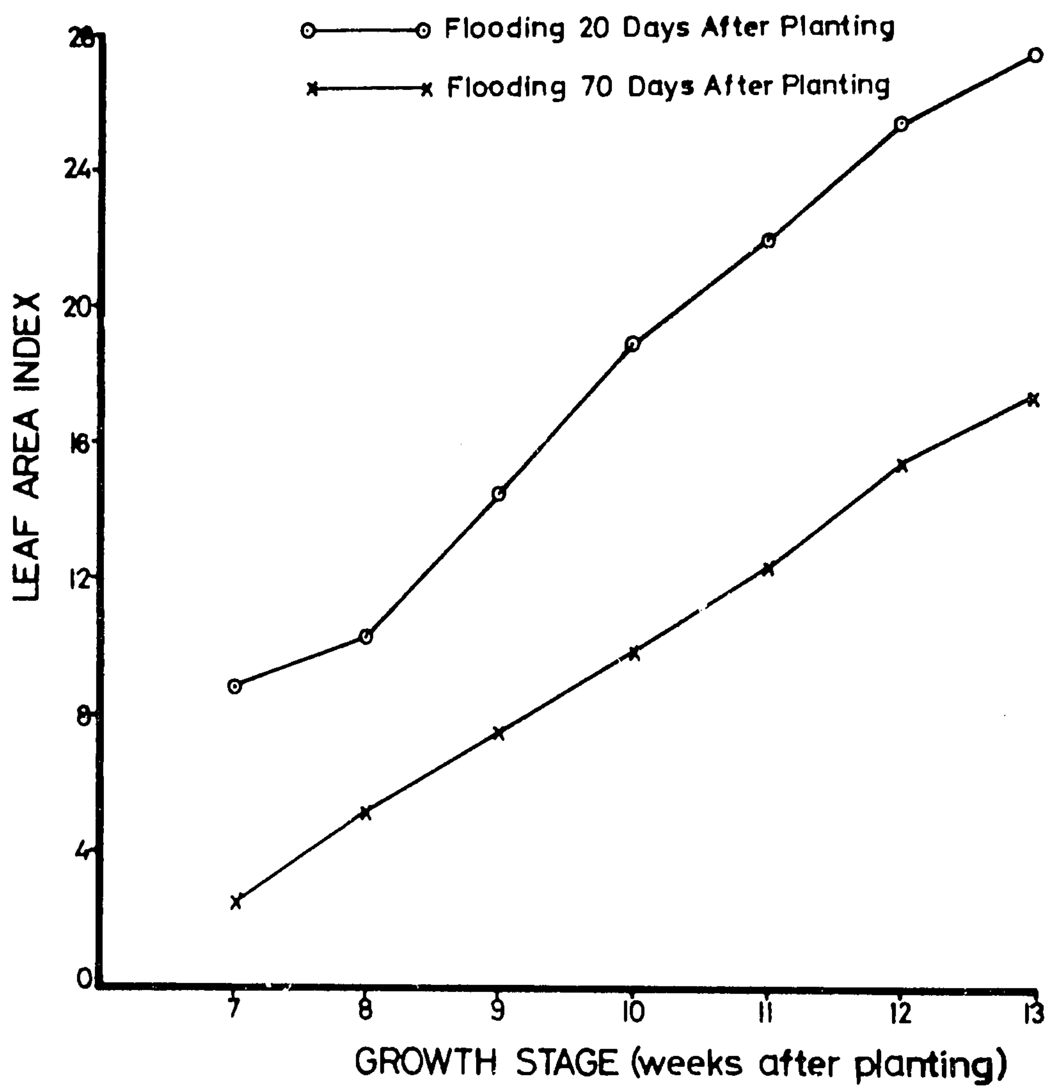

Fig.8. Leaf area index of OS-6 for flooding 20 and 70 DAS moisture regimes.

<u>Shoot growth</u>. Straw yield at harvest was significantly influenced by soil moisture stress in both varieties. In general, OS-6 had more straw yield than IR-20 at all moisture regimes. The lowest straw yield was obtained for 100 cm suction treatment (Table 5).

In case of IR-20, straw weight decreased with increase in suction from 25 to 50 and 100 cm. However, there was a slight increase in the straw weight as the suction increased from zero to 25 cm. Straw yield of IR-20 was also influenced by the duration of submergence. The submergence from 20-55 DAS had less straw yield, and similar to that of 100-cm suction.

The influence of soil moisture stress on the straw yield of OS-6 was less pronounced than in case of IR-20. An increase in soil moisture stress from zero to 100-cm suction had no effect on the straw weight of OS-6. But decrease in the length of submergence period significantly reduced straw yield compared with longer submergence durations. The straw yield, maximum plant height and the LAI had similar trends in relation to soil moisture regime (Table 5).

<u>Consumptive water use</u>. Consumptive water use for the two rice varieties under different soil moisture regimes is shown in Table 6. As expected, the consumptive use was the highest for various submergence treatments, followed by zero suction and 50-cm suction moisture regime. There are significant varietal effects on the consumptive water use. Because OS-6 can maintain more LAI and plant height at intermediate drought stress, its consumptive water use is also more than that of IR-20. Therefore, a close correlation exists between the LAI and consumptive water use. Also, consumptive water use for treatments with delayed submergence is not drastically lower than those with submergence from 20 DAS. Delayed submergence does not necessarily result in water saving; low suction does.

<u>Grain yield.</u> The comparison of the grain yield of four suction treatments with that of continuous submergence and different submergence duration for IR-20 and OS-6 is shown in Figure 9. OS-6 outyielded IR-20 at all the moisture regimes. Grain yield of OS-6 and IR-20 decreased with decrease in suction from zero to 100 cm. It may be justified to infer from these data that for sandy soils a suction value ranging from 25 to 50 cm is a threshold beyond which yield of rice declines significantly. The duration of submergence also had a significant but complex effect in terms of grain yield. There were no significant differences in grain yield among continuous submergence until submergence from 20-70 DAS or submergence from 20-90 DAS. But submergence from 20-55 DAS, followed by 100-cm suction at floral stage decreases grain yield. However, the relative decrease in yield was higher in IR-20 than in OS-6 (Table 7). The grain yield of treatments involving submergence only from 20-55 DAS, was equivalent to that of continuous soil moisture suction of 50 cm.

Table 5. Influence of soil moisture stress and delayed flooding on straw yield and plant growth.

Soil Moisture regime	Straw yield (g/pot)		Plant height (cm)		Maximum LAI	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence 20 DAS	221.7	303.7	99.7	201.4	26.7	27.4
Zero suction	225.3	264.3	82.1	190.2	25.5	26.3
25-cm suction	233.0	262.7	89.0	182.8	28.7	27.8
50-cm suction	188.0	262.3	79.9	174.0	20.3	22.7
100-cm suction	174.0	243.7	71.1	169.9	16.7	18.4
Submergence 20-55 DAS	183.3	255.3	76.9	171.3	20.8	24.7
Submergence 20-70 DAS	234.0	290.0	88.3	167.0	26.6	25.7
Submergence 20-90 DAS	207.3	312.0	90.5	196.7	26.8	29.3
F ratio	4.7**		107.9**		4.8**	
LSD (.05)	54.7		14.2		4.9	
SE	32.9		8.6		2.9	
CV (%)	13.6		6.4		12.0	

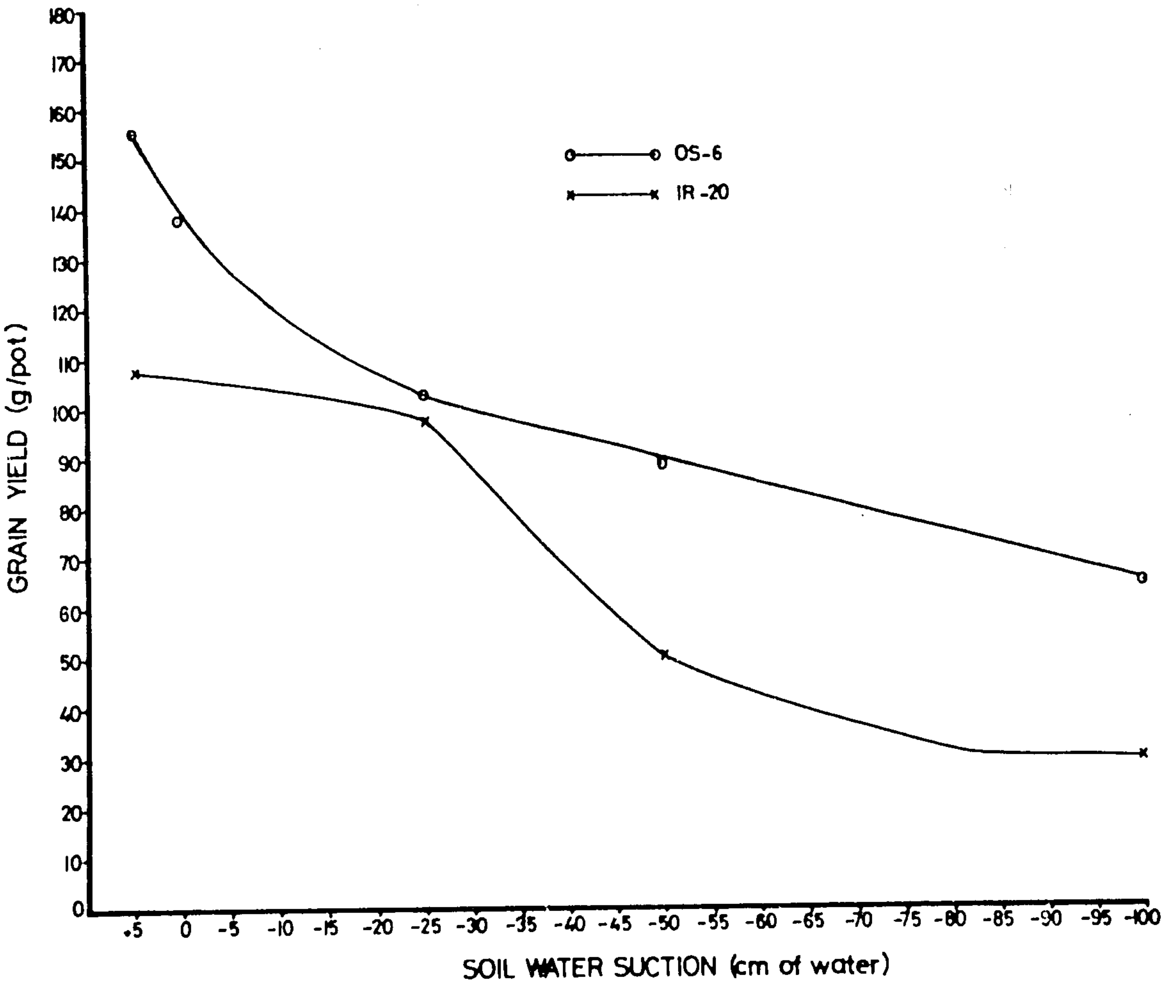

Fig.9. Effect of soil moisture suction on grain yield of IR-20 and OS-6.

Table 6. Influence of soil moisture stress and delayed flooding on consumptive water use (cm) at different growth stages of IR-20 and OS-6.

Soil moisture regime	20-50 DAS		20-70 DAS		20-90 DAS		20-120 DAS	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence 20 DAS	44.5	46.4	62.1	69.4	88.0	103.9	122.0	141.1
Zero suction	26.2	32.2	43.3	50.7	63.0	74.0	91.1	104.2
25-cm suction	25.2	27.1	42.7	45.8	67.1	71.6	98.3	106.7
50-cm suction	17.4	25.0	27.4	41.9	40.1	66.2	57.7	96.8
100-cm suction	15.4	16.5	25.5	29.5	36.0	46.4	49.8	79.3
Submergence 20-55 DAS	34.9	38.7	42.6	51.3	56.8	74.4	72.7	100.0
Submergence 20-70 DAS	41.3	43.7	56.9	60.8	72.6	86.1	99.1	118.0
Submergence 20-90 DAS	40.8	47.0	58.2	70.1	77.5	101.9	98.3	129.2
F. ratio	21.3**		13.7**		9.3**		5.5**	
LSD (.05)	6.9		10.8		18.4		29.8	
S.E.	4.1		6.5		11.1		17.9	
CV (%)	12.7		5.5		15.7		18.3	

Table 7. Influence of soil moisture stress and delayed flooding on yield and yield components of two rice varieties.

Soil moisture regime	Grain yield (g/pot)		Grain/panicle		Panicle length (cm)		Sterile grains (number)		Weight of 100 grains (g)	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence 20 DAS	108.6	155.9	107	130	24.1	29.2	12	11	14.5	25.0
Zero suction	112.6	137.4	92	118	22.1	30.6	13	15	14.5	26.0
25-cm suction	98.7	103.4	99	114	23.8	29.6	12	16	14.1	25.4
50-cm suction	49.3	89.1	70	108	21.4	27.8	16	21	13.8	21.5
100-cm suction	28.0	64.9	68	94	21.3	27.4	16	20	11.2	21.2
Submergence 20-55 DAS	42.1	87.4	68	93	21.4	26.9	10	14	13.6	25.6
Submergence 20-70 DAS	102.7	134.2	105	98	23.1	27.3	10	8	14.4	27.8
Submergence 20-90 DAS	96.8	151.2	118	142	23.2	30.1	12	13	13.4	24.5
F ratio	5.3**		3.7**		14.3**		2.9**		48.6**	
LSD (.05)	45.2		31		2.6		5.9		2.9	
SE	27.1		19.1		1.5		3.6		1.8	
CV (%)	28.5		18.8		6.0		25.6		9.2	

Influence of soil moisture regime on various parameters of yield components is shown in Table 7. Number of grains per panicle, panicle length, and unit grain weight were significantly more in OS-6 than IR-20 for all the moisture regimes investigated.

Number of grains/panicle followed similar pattern to that of grain yield. Soil moisture stress decreased the number of grains per panicle, as did the decrease in the duration of submergence. However, only soil moisture suction treatments of 50 and 100 cm significantly suppressed the number of grains/panicle. The lowest number of grains/panicle was observed for stress at panicle initiation (submergence 20-55 DAS) and for continuous suction of 100 cm.

Panicle length also decreased with increase in soil moisture suction and decrease in the duration of submergence. The smallest panicle length was observed for 100-cm suction and for the submergence of 20-55 DAS treatments. Floral sterility was also high for 100-cm suction treatment.

Unit grain weight in OS-6, sometimes doubled that of IR-20, particularly for the stressed treatments. Although soil moisture stress decreased the unit grain weight in both the varieties, the relative or percent decrease in IR-20 was significantly higher than that of OS-6.

Water Use Efficiency (WUE). Data in Table 8. show significant varietal and moisture treatment effect on the water use efficiency, defined as the grain yield per unit amount of water consumed. Generally OS-6 had significantly more WUE than IR-20, particularly when subjected to high soil moisture stress. The WUE of OS-6 was as much as 50% more than that of IR-20 for submergence from 20-55 DAS and for 100-cm suction treatments.

Soil moisture stress decreased the WUE in both the varieities. However, there was a significant increase in the WUE of IR-20 when comparing continuous submergence from 20 DAS and zero suction treatment. There was a similar, but not statistically significant, increase in the WUE of OS-6 for these two treatments. The maximum WUE was observed for zero suction treatment for both the varieties.

The maximum WUE for zero suction at 15 cm depth, once again supports the hypothesis that beneficial effects of continuous submergence are doubtful at best and harmful at its worst.

Table 8. Water use efficiency (g/cm of water) of grains as influenced by soil moisture stress and by delayed flooding.

Soil moisture regime	IR-20	OS-6
Submergence 20 DAS	0.833	1.060
Zero suction	1.250	1.290
25-cm suction	0.950	0.931
50-cm suction	0.870	0.820
100-cm suction	0.570	0.753
Submergence 20-55 DAS	0.593	0.843
Submergence 20-70 DAS	0.927	1.070
Submergence 20-90 DAS	0.950	1.250
F ratio	3.18**	
LSD (.05)	0.309	
SE	0.186	
CV (%)	20.277	

Conclusion

The following conclusion can be made from the analysis of results obtained at IITA.

1. Zero suction, or saturated soil, can give yields equivalent to that with continuous submergence.

2. Continuous submergence throughout the growing period is not necessary for optimum yield.

3. Saturated soil or submergence only during the flowering stage is enough for high yields.

4. Even a suction of 100 cm at floral stage and submergence during the vegetative stage can result in significant yield reductions.

5. There is no significant difference in grain yield for 0 and 25 cm of water suction as compared with that of continuous submergence. Perhaps a low suction value of 25-50 cm, the air - entry pressure at which macro-pores begin to drain, is critical for yield depression.

6. The consumptive water use was influenced by soil moisture regime, and the highest WUE was observed for either zero or 25 cm suction or for submergence only from 20-90 DAP.

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7. SUBMERGENCE AND RICE YIELD

Submergence of rice field, by 5 - 10-cm depth of water, is widely practiced. Although rice requires saturated soil conditions for optimum growth, the reasons for submergence in standing water are not universally acknowledged. Weed control may be an advantage, and so may be the efficient use of applied fertilizer or of inherent soil fertility.

During submergence the chemical and physical characteristics of water can also affect rice growth.

Water temperature has been identified as an important factor in rice growth and yield by many workers. Kataoka (1969) related the water temperature in rice to the meteorological and hydrological characteristics at a given location. He reported higher average water temperature than the average daily air temperature. Chaudhry and Ghildyal (1970) studied the effects of soil temperature regime from 10°C to 40°C on rice growth and yield. The maximum emergence occurred at 25°C and 30°C. Rice seedling emergence decreased at lower temperatures of 15°C-20°C. In a two-year experiment with artificially maintained water depths of 5 cm and 20 cm on the Hungarian plains, Vamadevan (1971) investigated the effects of water depth on temperature at soil/water interface. The difference between the soil/water interface and the air temperature was found to be the greatest at the beginning of the growing season, and the rate at which it decreased was smaller with deep than with shallow water. Yield was also more with great water depth. The higher yield with greater water depth under Hungarian conditions could be attributed to higher temperature at the soil/water interface. This influence of temperature on rice was also shown in India when the cyclic temperature regime of 32°C/20°C showed better root growth and tiller development than plants growing at 26°C constant temperature (Chaudhry and Ghildyal, 1971). Similar studies conducted in the Philippines by Bhattacharya and De Datta (1971) indicated that higher temperatures accelerated the growth and development of plants. Grain yields were significantly decreased by a soil temperature of 15°C during panicle development. Ueki (1971) conducted similar experiments in Japan and reported that the water temperature above 30°C generally had a detrimental effect on growth. Hoshino et al (1972) reported a significant interaction between temperature and moisture regime on growth and development of rice. Similar to maize, Moriwaki (1974) reported that the most sensitive part of the rice plant to soil temperature is the shoot base.

The research conducted in India on the effects of depth of submergence on rice yield has been reviewed by Pande (1975). The results indicated that a shallow depth was generally beneficial in terms of yield obtained. The effect of submergence, however, is also related to water temperature, and to the evaporative demand of the atmosphere. Pande (1975) reported that during monsoon season the rice yield was similar for soil moisture conditions of saturation, and shallow and deep submergence. However, when grown during the periods of high evaporative demand, rice yield was adversely affected by non-submergence.

Certain experiments were conducted at IITA from May to November 1972 to compare yield of IR-20 under saturated soil conditions with that under continuous submergence, and to compare the effects of submergence at different growth stages. Under the conditions of these experiments at IITA, the temperature at the soil/water interface was never below a weekly mean of 23.9°C (Table 1). The maximum temperature under the rice canopy in water, or at the soil/water interface also never exceeded 35°C. Therefore the temperature probably was not a serious factor limiting rice production in these studies. The maximum temperature at the soil/water interface may be above the optimum level by 2°C-5°C for perhaps 2-4 hours per day.

Data in Table 1 shows that the minimum water temperature was higher than air temperature at least by 1 - 1.5°C in July, and 0.5°C - 1.0°C in August and September. The minimum temperature at the soil/water interface was higher than the water temperature by about 0.5°C. The minimum temperature at the soil/water interface did not increase for the duration of this experiment. It is possible therefore that most of the incoming radiation was used toward evapo-transpiration. The heat flux into the soil itself was, therefore, minimal.

The influence of continuous submergence on grain and straw yield of IR-20 rice was compared with saturated soil but no submergence, and with submergence super-imposed on saturated soil at various growth stages. The moisture regime treatments consisted of:

(i) Submergence from 20 DAS.

(ii) Submergence only during 20-35 DAS, saturated soil before and after.

(iii) Submergence only during 20-55 DAS, saturated soil before and after.

(iv) Submergence only during 20-70 DAS, saturated soil before and after.

(v) Submergence from 70 DAS, saturated soil before that.

(vi) Saturated soil, no submergence.

Table 1. Weekly mean soil and water temperature (C) under paddy in relation to air temperature at 7.30 am.

Measuring site	July 1972				August 1972				September 1972
	1-7	8-15	16-23	24-31	1-7	8-15	16-23	24-31	1-7
Air	23.5	23.7	23.6	23.5	23.0	22.7	23.0	23.3	23.5
Water	25.1	25.2	25.0	24.5	24.2	23.5	23.6	23.7	23.9
Soil	25.9	25.7	25.5	25.0	24.8	24.0	23.9	23.9	24.2

Plant height. Influence of soil moisture regime on plant height is shown in Table 2. There were no significant effects of these moisture regimes on plant height at any stage of growth. Longer duration of submergence, however, seemed to encourage plant growth. The height was shortest for submerged treatment and for the treatment with submergence in the vegetative stage e.g. from 20 to 35 DAS.

Tiller count. Numbers of tillers per m^2 were affected more by the soil moisture regime than the height measurements (Table 3). The least number of tillers was observed for the unsubmerged treatment, and for the one submerged for the shortest duration e.g. 20 - 35 DAS. The results, however, were not statistically significant. Tiller count showed consistent trends in connection with moisture regimes from about 35 DAS to 90 DAS. The maximum tiller count was observed at 90 DAS.

In general, plant vigor as monitored by height and number of tillers was not affected by submergence, as long as the soil was kept near the saturation level.

Straw yield. The straw yield is shown in Table 4. Straw yield was significantly affected by soil moisture regime. The highest straw yield was obtained for the continuously submerged treatment, and the second highest yield was produced in the treatment with submergence from 70 DAS to maturity. The least straw yield was obtained for the unsubmerged treatment and those treatments submerged only for the short duration.

The relative decrease in straw yield was 36 and 30 percent, respectively by decreasing the submergence duration gradually from 20 to 35 DAS, and no submergence at all. Relative straw yield for different submergence duration relative to that of continuous submergence was 0.64, 0.73, 0.89, and 0.95, respectively for submergence from 20-35 DAS, 20-55 DAS, 20-70 DAS and submergence from 70 DAS to maturity. Submergence, therefore, significantly improves vegetative growth in rice plant. Similar results have been reported by other workers.

The final plant height at harvest was identical to the straw yield, and was significantly different among various moisture regimes (Table 4). The final plant height was in the order of submergence 20 DAS>submergence 20-70 DAS>submergence 70 DAS>submergence 20-35 DAS>submergence 20-55 DAS and no submergence. The relative plant height in the same order was 1.00, 0.99, 0.96, 0.93, 0.91. Submergence, therefore, significantly increased the final plant height and the total straw yield.

Grain yield and yield components. The rice grain yield and yield components shown in Table 5, indicate significant differences due to moisture treatments. The lowest grain yield was obtained for the unsubmerged treatment. There were no significant differences in grain

Table 2. Influence of submergence time on plant height and shoot growth.

Soil moisture regime	Plant height (cm) at different DAS								
	35	42	49	56	60	70	77	84	91
Submergence 20 DAS	30.7	38.3	54.0	56.7	65.0	72.0	80.7	85.3	91.0
Submergence 20-35 DAS	30.7	38.7	53.0	57.7	63.0	70.0	76.3	80.3	87.3
Submergence 20-55 DAS	30.3	36.0	52.0	54.3	61.0	67.0	76.0	79.7	86.3
Submergence 20-70 DAS	29.7	39.0	54.3	59.7	66.0	74.0	86.3	89.0	94.0
Submergence 70 DAS	29.7	36.0	48.7	55.7	60.0	67.3	78.7	80.3	89.3
Zero suction, no submergence	30.0	36.0	49.3	56.3	56.0	64.7	76.7	81.3	87.3
LSD (.05)	n.s	3.6	8.2	n.s	19.1	n.s	n.s	n.s	n.s

Table 3. Influence of submergence time on tillering behavior of IR-20 in the field (x10^2).

Soil moisture regime	Tiller number per m^2 at different growth stages (DAS)								
	35	42	49	56	63	70	77	84	91
Submergence 20 DAS	13.2	14.7	15.2	15.8	17.0	18.3	18.7	18.9	19.0
Submergence 20-35 DAS	13.3	13.7	14.5	15.2	16.1	17.0	17.3	17.7	17.9
Submergence 20-55 DAS	12.7	15.7	16.2	16.7	17.8	18.9	19.4	19.6	19.8
Submergence 20-70 DAS	13.2	15.3	15.7	16.5	17.5	18.3	18.8	19.1	19.3
Submergence 70 DAS	12.7	15.7	16.1	16.5	17.9	18.4	18.6	18.8	19.0
Zero suction, no submergence	12.5	13.6	14.1	14.8	16.0	17.1	17.6	17.9	18.2
LSD (.05)	2.5	2.4	2.6	0.7	1.4	2.1	2.3	1.9	1.7

Table 4. Straw yield and the final plant height of rice as influenced by soil moisture regime.

Soil moisture regime	Straw yield* (T/Ha)	Final plant height (cm)
Submergence 20 DAS	7.56	106.4
Submergence 20-35 DAS	4.81	99.4
Submergence 20-55 DAS	5.50	97.4
Submergence 20-70 DAS	6.71	105.8
Submergence 70 DAS	7.16	101.6
No submergence, saturated soil	5.29	99.1
LSD (.05)	1.90	7.8

* on oven dry basis

Table 5. Influence of soil moisture regime on grain yield and yield components.

Soil moisture regime*	Grain yield T/Ha	Panicle length cm	Grain of panicle	Floral sterility %	Weight of 1000 grains g
Submergence 20 DAS	4.36	24.4	109	17.8	16.8
Submergence 20-35 DAS	4.81	25.2	112	16.1	16.4
Submergence 20-55 DAS	4.25	24.7	116	18.4	16.5
Submergence 20-77 DAS	4.72	25.6	130	15.5	17.3
Submergence 70 DAS	4.29	25.7	135	20.2	15.8
No submergence	3.44	24.8	121	17.3	15.2
LSD (.05)	1.10	1.6	18	4.0	1.9

* Soil was kept saturated in all the treatments both before and after submergence.

yield among other treatments. Submergence, even for a short duration at pre-flowering or during the flowering stage was enough to produce the optimum grain yield. The unsubmerged treatment with saturated soil produced 23 percent lower yield than the mean yield of the remaining treatments. The relative grain yield was in the order of 1.00, 0.98, 0.91, 0.89, 0.88 and 0.72 respectively for the moisture regime of submergence from 20-35 DAS, submergence 20-70 DAS, submergence 20 DAS, submergence 70 DAS, submergence 20-55 DAS, and no submergence. The highest grain yield, however, was not obtained for the continuously submerged treatments. Submergence imposed from floral initiation stage onward produced grain yield equivalent to that of the continuously submerged treatments.

The analysis of the yield components in relation to total yield indicate that there were no significant differences in the panicle length, floral sterility or in number of grains per panicle as a result of moisture regimes imposed in this study. The major differences in grain yield occurred in the unit grain weight and perhaps in the number of productive tillers (Tables 3, 5).

The unit grain weight was the lowest in the unsubmerged treatment and in the one with submergence imposed only from 70 DAS. Submergence during the floral initiation stage, therefore, seems to be important in the proper grain development. The number of grains per panicle was also significantly affected by the soil moisture regime.

The highest numbers of grains per panicle were recorded for treatments involving submergence during and just before the floral initiation stage. Continuous submergence, perhaps due to severe leaching losses of applied N, produced the least number of grains per panicle, even lower than the unsubmerged treatment. The relative number of grains per panicle were in the order of 1.00, 0.96, 0.90, 0.86, 0.83, 0.81, respectively for submergence 70 DAS, submergence 20-70 DAS, submergence 20-35 DAS, and submergence from 20 DAS.

Floral sterility was not significantly affected by soil moisture regime. The highest sterility percentage was observed for the treatment involving submergence only after the floral initiation stage. The lowest floral sterility was observed for those treatments which involved submergence through the floral development stage and prior to it.

It may be justified to conclude that optimum yield is obtained if the soil were kept near saturation at all stages and submerged during the maximum tillering and flowering stage or panicle development stage. Similar results have also been reported by many researchers.

Conclusions

The results reported in the previous section indicate that:

(i) Temperature at the soil/water interface under conditions similar to that of IITA, Ibadan is probably not a significant factor affecting rice growth and yield.

(ii) Non-flooded soil kept at near saturation yielded 20 percent less than the submerged treatments. This depression in grain yield of the unsubmerged treatments is attributed to the unsaturated conditions prevalent in this treatment during long rainless periods. Another important factor is the drainage of the excess water. The plants generally appeared to be chlorotic. Perhaps draining of the rain water depleted the soil of its essential nutrients, such as nitrogen. If the nitrogen losses in the drained water were compensated for, the yield difference might be negligible.

(iii) The influence of submergence on yield was probably through the increase in number of productive tillers, increase in the panicle length, and an increase in the unit grain weight.

(iv) Submergence for a short duration only during maximum tillering and panicle development and floral initiation stages may be adequate for optimum yield.

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8. MECHANISM OF RICE RESPONSE TO MOISTURE STRESS

Improvements in upland rice production which is the predominant system of rice production in West Africa and parts of Latin America, can be made by understanding the basic parameters of soil-plant-water relationships. Criteria for a selection of suitable varieties for upland conditions can be developed through understanding of basic soil-water relations and rooting characteristics. From the results presented in the previous chapters concerning water relations under flooded conditions, it can be generalized that optimum yields can be obtained without continuous submergence, provided soil is kept near saturation during critical growth periods. Beginning with this chapter, an analysis will be presented for conditions applicable to upland rice. Emphasis will be given to the factors which influence "critical soil moisture potential" in relation to leaf moisture potential, stomatal behavior and consumptive water use of various rice varieties grown under different levels of soil moisture stress. The results presented will be generalized to outline the principles of field and greenhouse techniques for varietal selection against drought and moisture stress.

Water stress in plants is a major factor limiting crop production. Through a wide range of investigations (Shaw and Laing, 1965; Denmead, 1960; Laude, 1957; Viets, 1970; and Slatyer, 1967), it has been shown that water deficiency is not only an important factor affecting economical yields in the regions with prevalent dry conditions, but also in the humid to sub-humid environments. Sometimes serious yield reductions can occur even without the plants showing wilt symptoms. Generally, wilt is not the first warning sign of water deficiency. Moderate water stress affects physiological activity and can decrease growth, development and yield (Slavik, 1963).

The response of plants to various levels of moisture stress is affected by soil and climatic factors, and also by the adaptability of various genotypes and cultivars to different ecological conditions. Thus among plants in the same species, varietal characteristics play an important role in plant response to water stress. A knowledge of the varietal characteristics that can be important for drought tolerance is an important area of genetic research in soil-plant-water relationships.

Tanaka, Kawano and Yamaguchi, (1966) reported high initial growth rate in rice when grown under adequate water supply followed by a decline in the growth rate at later stages of development. Although, when grown under the conditions of inadequate water supply. the initial growth rate is low; it stays constant even toward the later stages of development. This implies that the drought stress in rice, and perhaps in other cereals also, affects both the vegetative and reproductive stages of growth. The period of vegetative growth is significantly prolonged in favor of the reproductive phase of development. That is the basis of the conclusion arrived at by many researchers, that the maximum yield potential exists when the soil is maintained under flooded or saturated conditions (De Datta, Levine and Williams, 1970). These workers have also observed that although height of the rice plant is directly related to the depth of water in the paddy, tiller number appears to be inversely related to a relatively wide range of soil moisture conditions. Similar results were reported earlier in this book. However, if the soil moisture stress is increased, say, up to initial leaf rolling during hot periods, the tiller number reduces significantly. It is generally believed that grain to straw ratio is not affected by water management practices. Vergara (1970) stated that grain yield of the rice plant is a function of three yield components; (1) number of panicles per plant, (2) number of filled spikelets per panicle and (3) the unit grain weight. What influence does the moisture stress have on these components is not well understood and deserves to be a research priority. It has been shown in Chapters 3 and 4 that there is a sharp decline in yield of rice as in the soil moisture stress is increased from submerged treatment through zero and 250 cm suction at 15-cm depth. The beneficial effects of delayed submergence or a small degree of moisture stress in the vegetative stage (as might exist in a saturated, but not submerged soil) on grain and straw yield may be attributed to "hardening".

The yield components that are affected by moisture stress, and therefore can be used as criteria for screening against drought stress are sterility percentage, unit grain weight, and panicle number. A series of experiments conducted at IITA in 1972 to evaluate the effects of drought stress on the yield components of a few standard varieties are described in this chapter.

A greenhouse experiment was initiated in October 1972 with the following objectives:

(i) To investigate the influence of low level of soil moisture stress on growth and yield of two rice varieties, and

(ii) To compare growth characteristics of OS-6 and IR-20 to delineate parameters that may be desirable for upland rice environments.

The moisture treatments investigated consisted the following:

(i) Submergence to a 5-cm depth

(ii) Saturated soil, no submergence

(iii) Zero suction at 15-cm depth

(iv) 25 cm suction at 15-cm depth

(v) 50 cm suction at 15-cm depth

(vi) 75 cm suction at 15-cm depth

(vii) 100 cm suction at 15-cm depth

(viii) 250 cm suction at 15-cm depth.

Cumulative soil moisture stress was computed by plotting the daily tensiometric readings in cm (suction) over the entire growth period and then determining the area under the curve. This procedure was adopted for all the soil moisture regimes which were not submerged. The unit for this cumulative stress is cm-days and can be converted to bar-days or atmosphere-days. The amount of water added for each of the irrigation treatments and details of methodology are shown in Appendix 8.

The analysis of variance table of F ratio (Table 1) reveals the moisture and varietal effects on most of the observations made in this study. Table 1 shows that grain yield, straw yield, number of grains per panicle, panicle number per pot, panicle weights, days to flowering, tillers per plant, and total water use, have highly significant varietal and moisture regime effects.

The effects of various levels of soil moisture regimes on grain and straw yield, panicle number per pot, panicle weight, grain weight, dry matter production at different stages of growth, days to flowering, plant height, sterile grains per panicle, and total water use have also been found to be highly significant. The interaction between variety and moisture treatments is significant only for grain weight and for the number of days to heading.

The correlation and regression analyses conducted here have shown a highly significant correlation between water use and grain, and straw yield, grains per panicle, panicle weight, and plant height. Also the grain yield has been found to be significantly correlated with straw yield, and grains per panicle. Grain yield, plant height, root number and root weight were also significantly correlated with total water use (Table 2).

<u>Consumptive water use</u>. Figures 1-6 show the effects of various levels of moisture stress on the total amount of water used by each rice variety. Figure 1 shows the effect of cumulative moisture stress on centimeter of water used per pot. OS-6 had used a significantly higher amount of water than IR-20. However, for both varieties, the higher the cumulative stress the less was the consumptive water use. The consumptive water

Table 1. Analysis of variance table of F ratio

Source of variation	Grain yield	Grains/ panicle	Panicle/ pot	Panicle weight	Unit grain weight	Straw yield	Straw weight at mid-tillering	Straw weight at grain-filling	Height at tillering	No. of tiller	Days to heading	Days to 50% flowering	Sterile grains/ panicle	Sterile grains/ plant	Total water use	Final height
Variety (V)	48.8**	31.8**	137**	339**	0.7	134**	33.5**	48.1**	0.5	119**	107**	98.6**	21.8**	0.07	80.8**	0.6
Moisture regime (M)	8.6**	1.6	3.9**	2.3*	2.8*	8.3**	3.6	13.5**	6.9**	1.7	11.7**	21.5**	3.8**	1.8	19.0**	4.4**
VXM	1.4	0.4	0.5	1.7	4.1**	0.5	1.4	0.9	1.3	0.2	3.7*	0.3	2.2	0.9	0.5	1.6

Table 2. Correlation coefficients among various parameters

Parameters	Grain yield	Straw yield	Grain/ panicle	Panicle/ pot	Panicle weight	Unit grain weight	Straw weight at mid-tillering	Straw weight at grain-filling	Days to first heading	Days to 50% flowering	Tillers/ plant	Plant height at flowering	Plant height at harvest	Total water use
Grain yield	-	0.88	0.63	-0.08	0.53	0.58	[illegible]	0.79	-0.04	-0.05	-0.09	0.64	0.61	0.93
Straw yield			0.63	-0.29	0.71	0.71	0.81	0.81	0.26	0.17	-0.32	0.79	0.78	0.92
Grain/panicle				-0.35	0.64	0.58	0.49	[illegible]	0.21	0.14	-0.33	0.63	0.61	0.58
Panicles/pot					0.63	-0.78	-0.17	-0.07	-0.63	-0.59	0.95	-0.73	-0.76	0.06
Panicle weight						0.13	0.54	0.50	0.46	0.40	0.70	0.87	0.90	0.57
Unit grain weight							0.54	0.49	0.58	0.53	-0.79	0.94	0.97	0.56
Straw weight at mid tillering								0.76	0.06	0.52	-0.18	0.60	0.59	0.79
Straw weight at grain filling									0.02	-0.11	-0.10	0.60	0.58	0.87
Days to first heading										0.85	-0.61	0.48	0.57	-0.08
Days to 50% flowering											-0.53	0.40	0.48	-0.11
Tillers/plant												-0.75	-0.78	-0.1
Plant height at flowering													0.96	0.67
Plant height at harvest														0.61

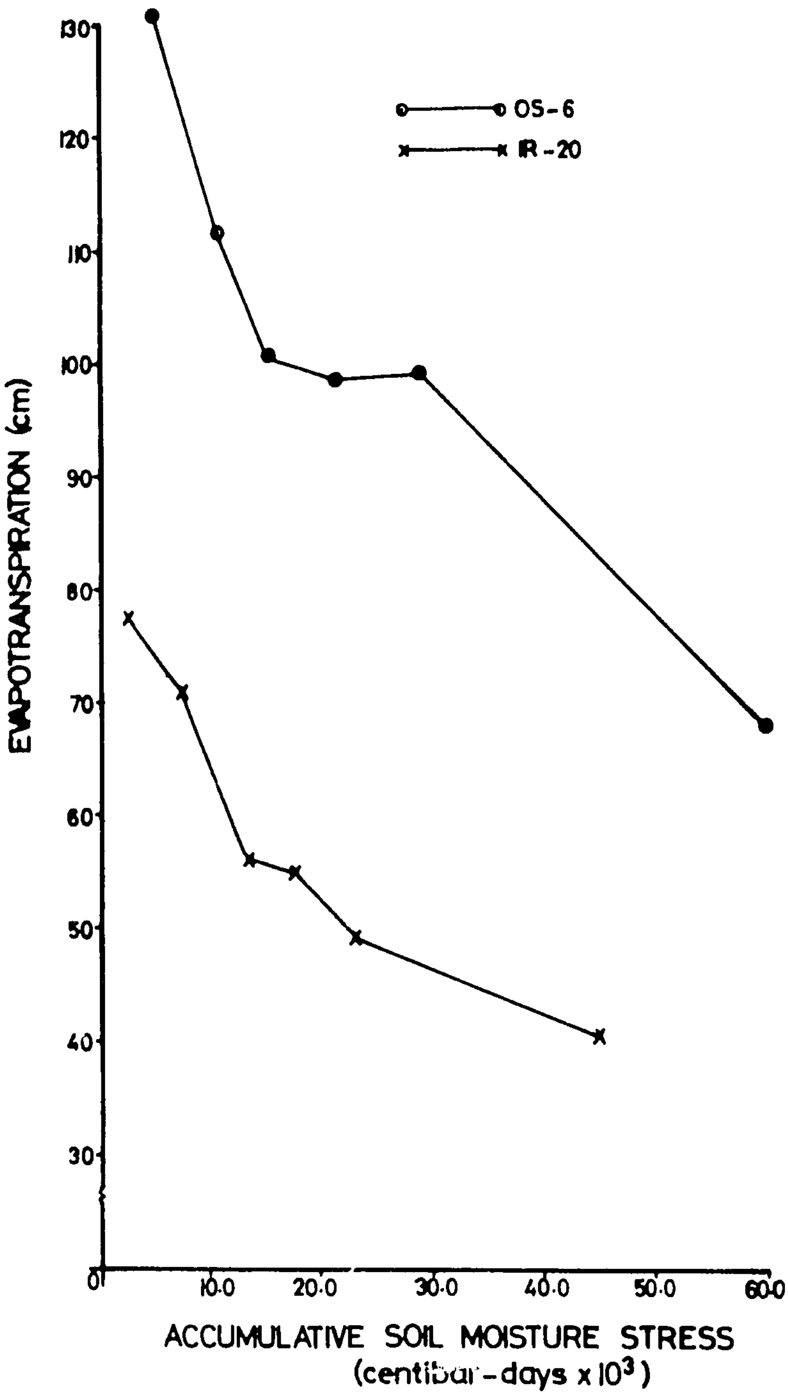

Fig.1. Effect of soil moisture stress on evapotranspiration of IR-20 and OS-6.

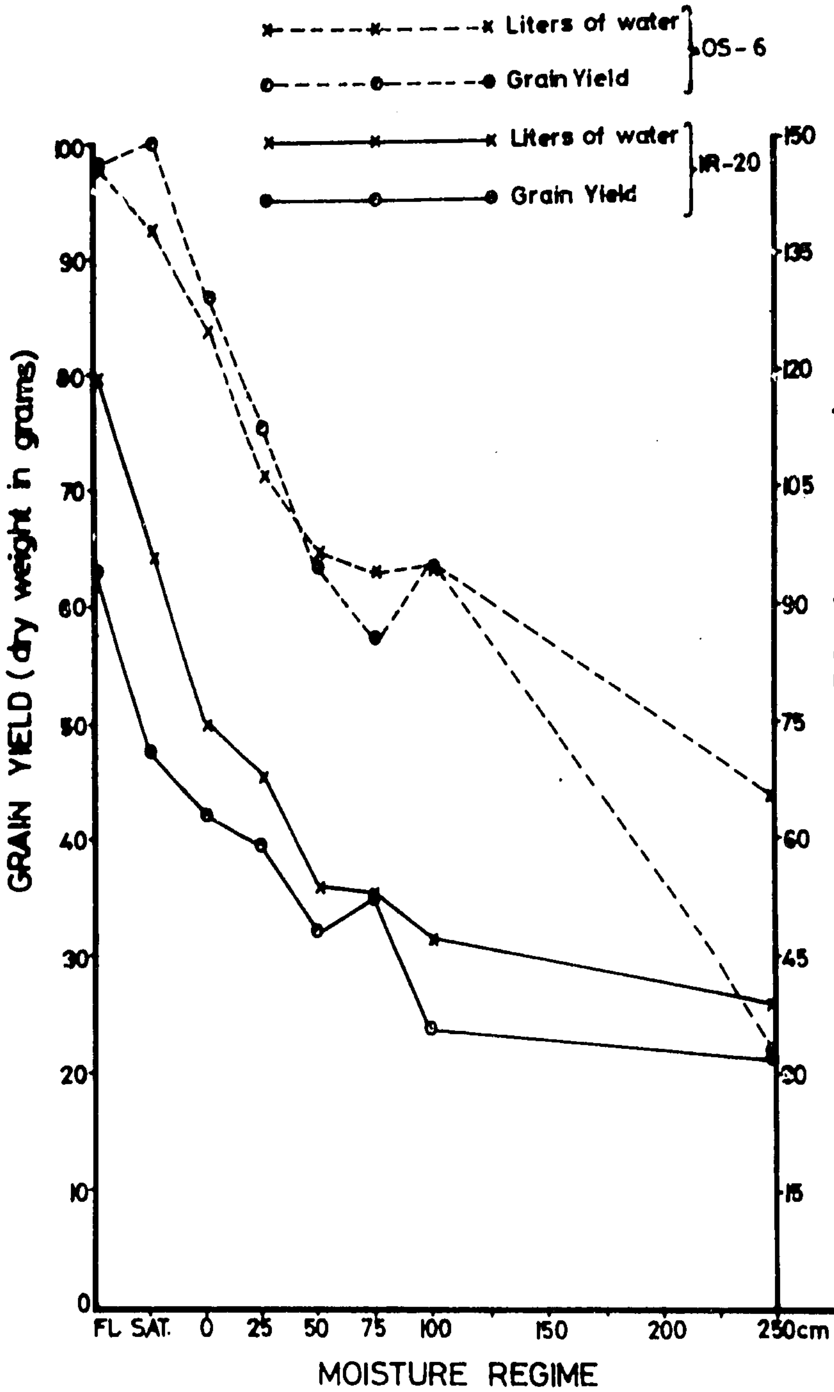

Fig.2. Effect of soil moisture regime on water use and grain yield of IR-20 and OS-6.

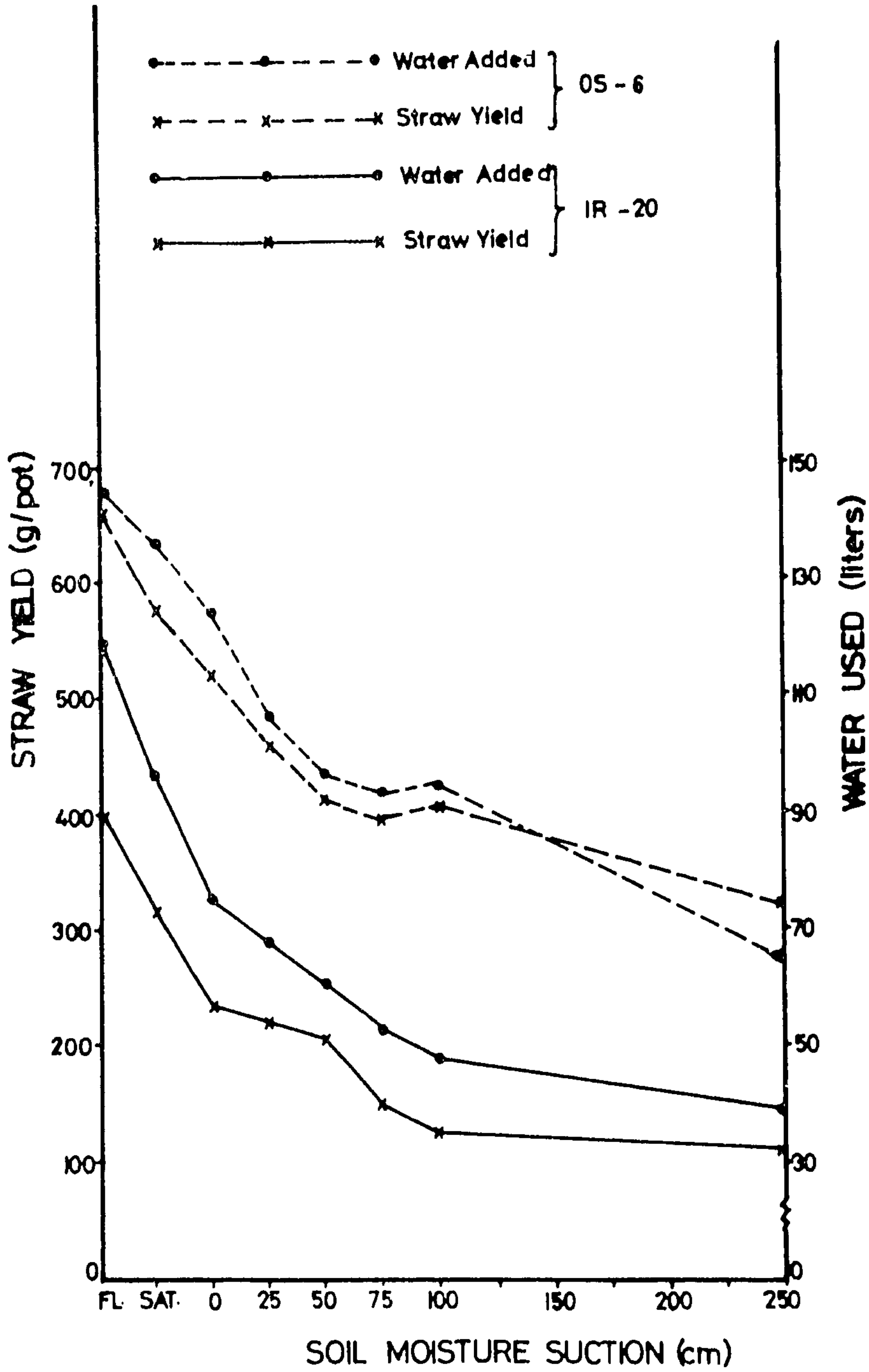

Fig.3. Effect of soil moisture regime on water use and straw yield of IR-20 and OS-6.

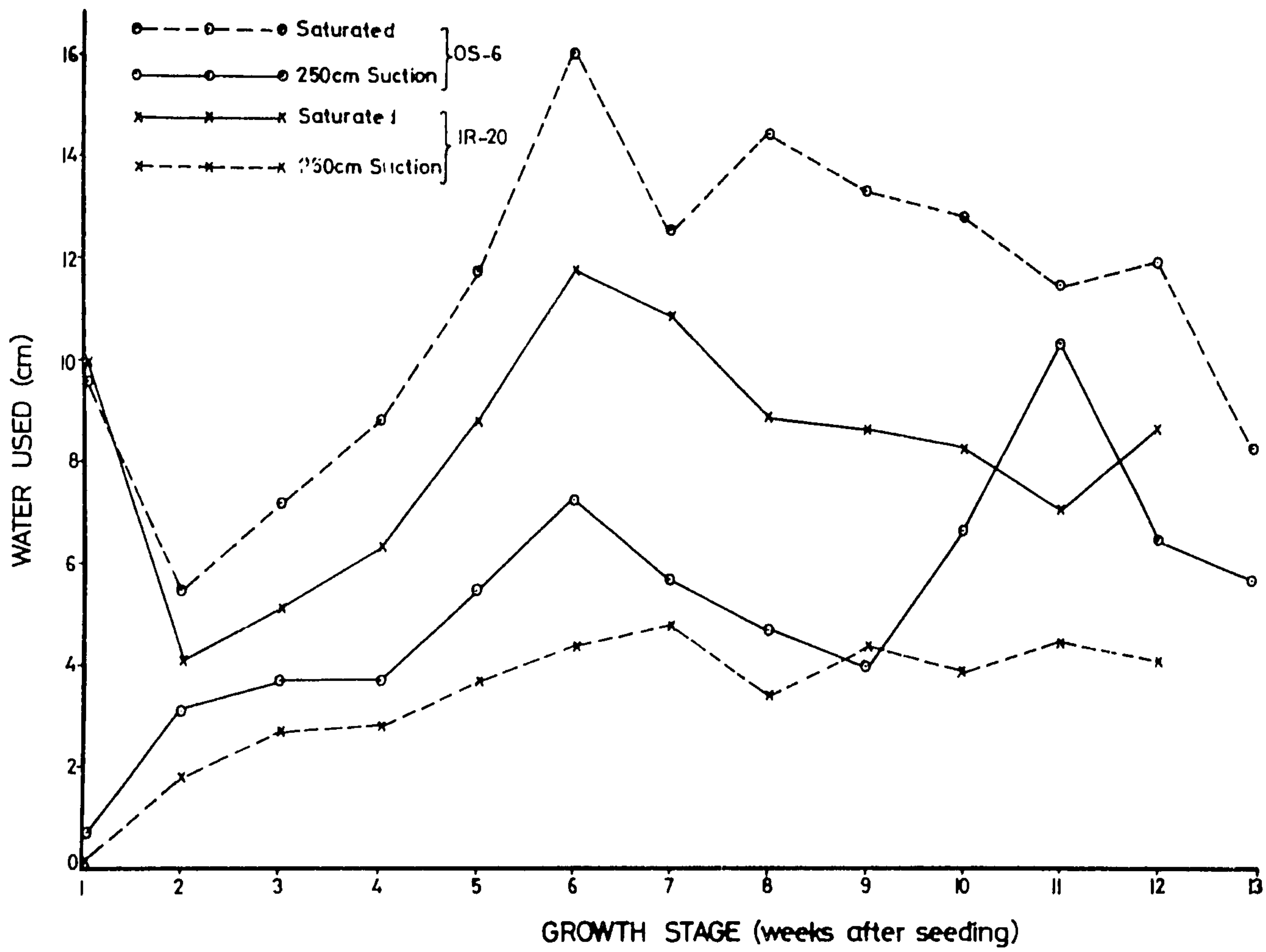

Fig.4. Effect of soil moisture regime on consumptive water use of IR-20 and OS-6 for different growth stages.

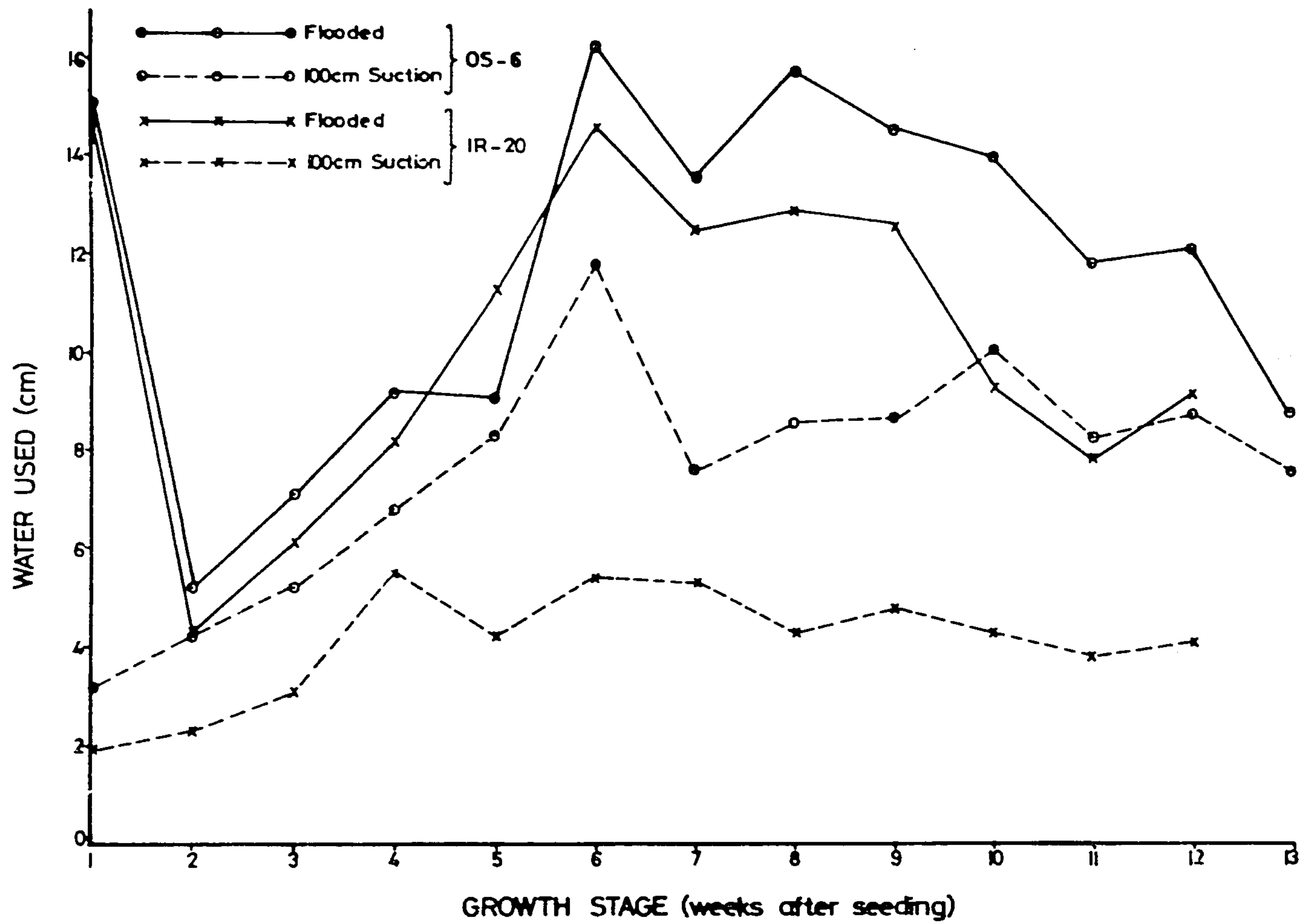

Fig.5. Effect of soil moisture regime on consumptive water use of IR-20 and OS-6 for different growth stages.

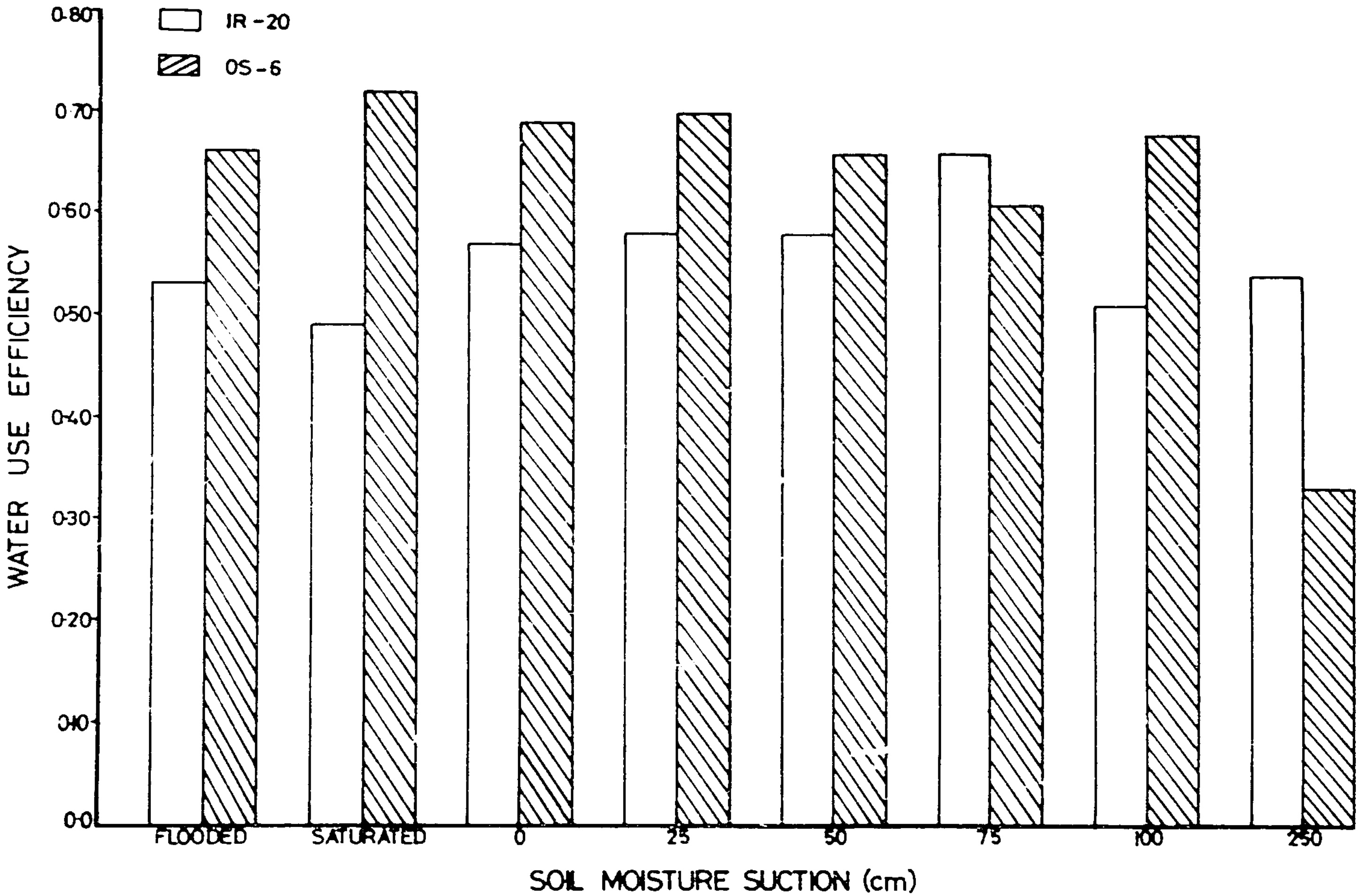

Fig.6. Effect of different soil moisture regimes on water use efficiency of IR-20 and OS-6.

use of IR-20 was 59 percent that of the OS-6 under various stressed treatments. The decrease in consumptive water use of IR-20 and OS-6 at high stress was 50 percent.

Figures 2 and 3 compare the total amount of water used, with the grain and straw yield of IR-20 and OS-6 rice under the various moisture regimes. Figure 2 indicates the beneficial effect resulting from a slight moisture stress for OS-6 under a saturated soil. The OS-6 variety had consistently higher grain and straw yield per unit quantity of water used. But at high moisture deficit, IR-20 had higher water use efficiency as measured in terms of grain and straw yield per unit quantity of water used (Fig. 3).

Figures 4 and 5 depict the water consumption of both varieties under high and low water regimes (saturated and 250-cm suction and flooded and 100-cm suction treatments). There was a gradual rise in the water use of both varieties with the increase in the stage of crop followed by a definite decline in consumptive water use toward maturity. IR-20 grown at high drought stress showed a constant water requirement, indicating a constant growth rate. For plants under saturated and flooded treatments, the peak water consumption occurred between 6th and 9th weeks after planting. The period coincides with the most active vegetative growth (maximum tillering) and actively flowering growth phases. The variety OS-6 grown under high drought stress did not show a constant water requirement and it peaked at the flowering stage. But the plot of the evapo-transpiration with time indicates that rice plants have the greatest water demand at the most active vegetative periods followed by high water demand at the flowering time.

Figure 6 depicts the water use efficiency of both IR-20 and OS-6 rice. The data indicate superiority of OS-6 over IR-20 in the efficiency of water use for plants grown under optimal water conditions (i.e. submerged and saturated soils). Under high moisture stress (250 cm suction), the water use efficiency of both OS-6 and IR-20 was identical. There were no significant differences in water use efficiency among different water regimes investigated.

Plant height. Figures 7-9 summarize the results of height measurements and tiller counts observed at different growth stages for both IR-20 and OS-6. In Figure 7, the advantages of saturated but unsubmerged soil over submerged and other soil moisture regimes during the vegetative stage for the height of OS-6 are evident. Whereas in IR-20 there was a 4 percent decline in the plant height as the soil moisture regime was changed from zero suction to 50-cm suction, there was a slight increase in the height of OS-6. The relative decrease in plant height from zero suction to 50-cm suction was 9 and 1 percent, respectively for OS-6 and IR-20. The maximum decrease in plant height occurred between the suction

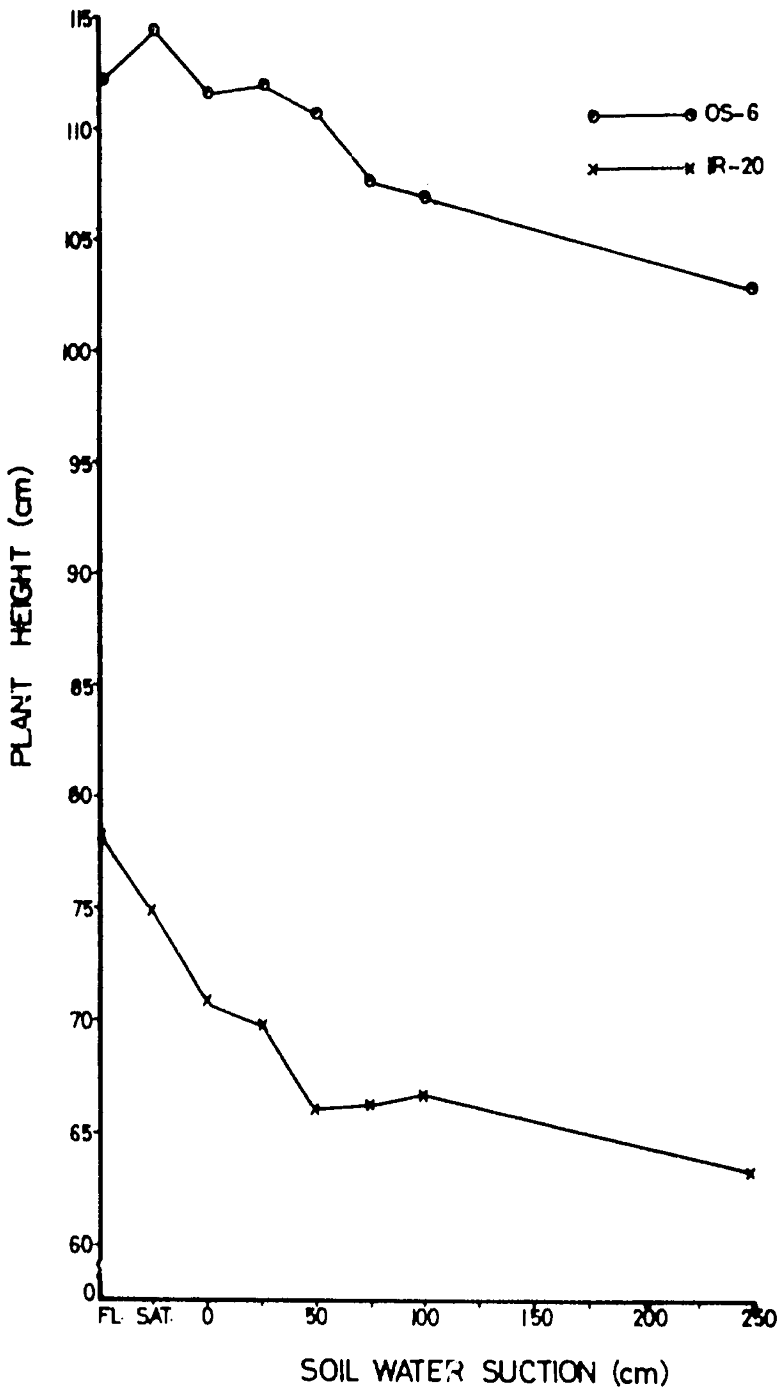

Fig.7. Effect of soil moisture regime on plant height of IR-20 and OS-6 at harvest.

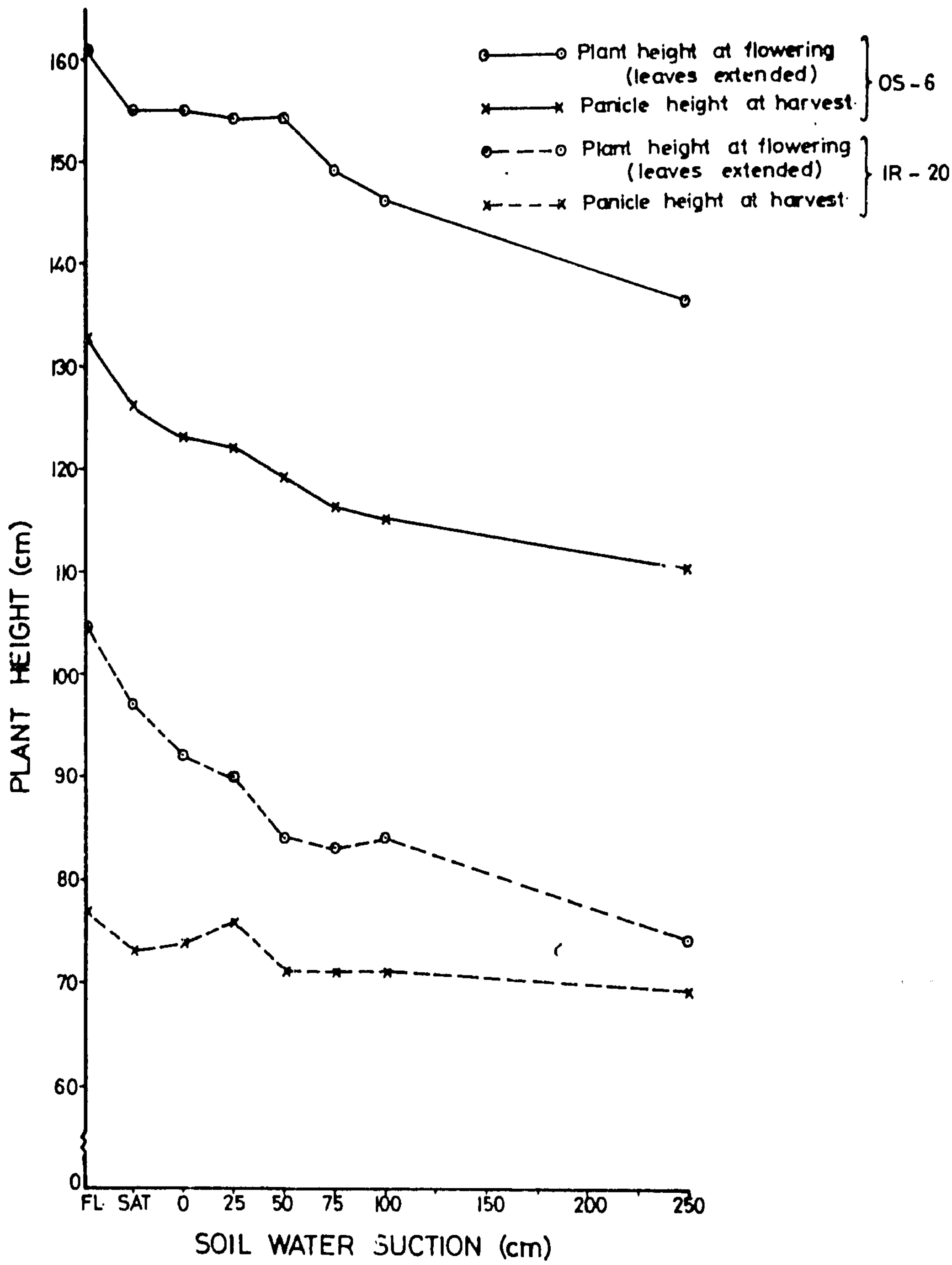

Fig.8. Effect of soil moisture regime on plant height of IR-20 and OS-6 at two growth stages.

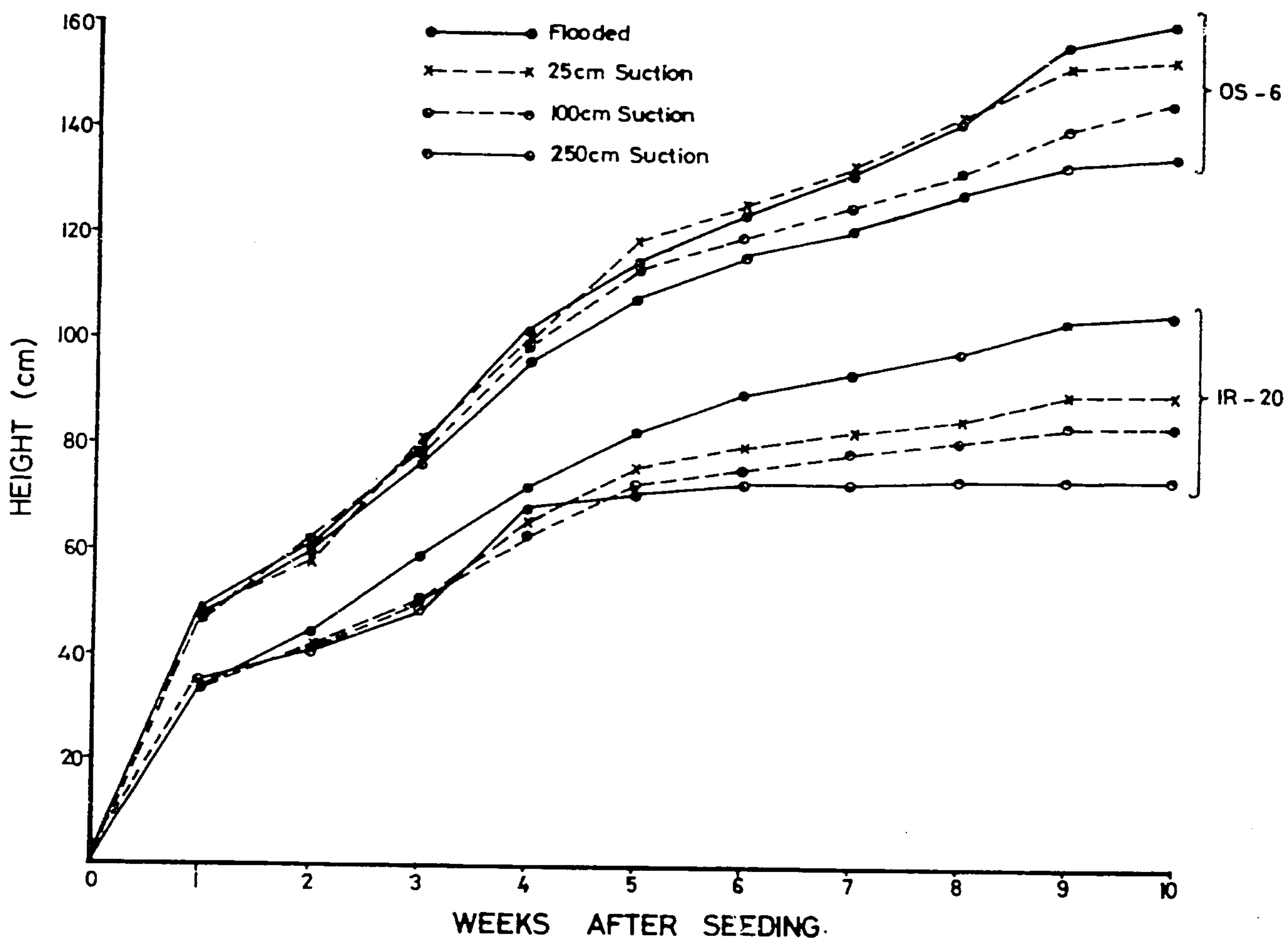

Fig.9. Effect of soil moisture regime on plant height of IR-20 and OS-6 at different growth stages.

ranging from zero to 50-cm. Figure 8 shows a similar response of IR-20 and OS-6 in terms of their height at flowering and harvesting. The relative decrease in height for final or up to panicle stage respectively was 11.9 and 17.3 percent for OS-6 compared with 29.5 and 10.4 percent for IR-20. With increase in stress, there was more decrease in the height of panicle development for OS-6 than that of IR-20 (Fig. 8).

General growth response of IR-20 and OS-6 is shown in Fig. 9 for soil moisture regimes of submergence and suctions of 25, 100 and 250 cm. As expected, beginning from the first week after planting, OS-6 plant grew higher than IR-20 for all the moisture regimes compared. For OS-6 the growth rate was consistent with the moisture treatments. Plant height and vigor of IR-20 declined significantly even at a slight moisture stress. Under a high moisture stress (250-cm suction), IR-20 ceased growth as from 4th week after planting, while OS-6 grew slightly but steadily until maturity. Another important observation in Fig. 9 is the comparison of plant height of IR-20 and OS-6 for moisture regimes of submergence and 25-cm suction. Until the 9th week, there were no differences in plant height of OS-6 between these two treatments. On the other hand, there was a significant decline in the height of IR-20 from the first week after imposing the moisture treatments.

Tiller count. Figure 10 shows the effect of moisture regimes on tiller production of IR-20 and OS-6. In general, IR-20 produced more tiller than OS-6 for all the moisture regimes. There are, however, significant differences among IR-20 and OS-6 response to moisture stress for tiller production. For IR-20 the average number of tillers per plant declined with an increase in moisture stress from zero to 75-cm suction, remained constant until 100-cm suction and then decreased significantly with increase in soil moisture stress from 100-cm to 250-cm suction. High soil moisture stress, therefore, prolonged or accelerated vegetative growth of IR-20.

For OS-6 with a fewer tillers, there was a gradual reduction in number of tillers as the soil moisture stress increased from zero to 50-cm suction. There was no change in tiller production with further increase in stress up to 250 cm of moisture suction. The relative decrease in tiller count with change in moisture regime from submergence to 100-cm suction was 33 percent in IR-20 compared with 40 percent in OS-6. OS-6 may produce fewer but productive tillers at high stress, as compared with more but unproductive tillers in IR-20.

Figures 11-14 depict the tiller production of rice under four moisture regimes throughout the growth periods. It is interesting to note that for the submerged treatment, the maximum tiller production in OS-6 was obtained in the 5th week and in IR-20 in the 7th week. However, with the increase in stress, the number of tillers kept increasing even

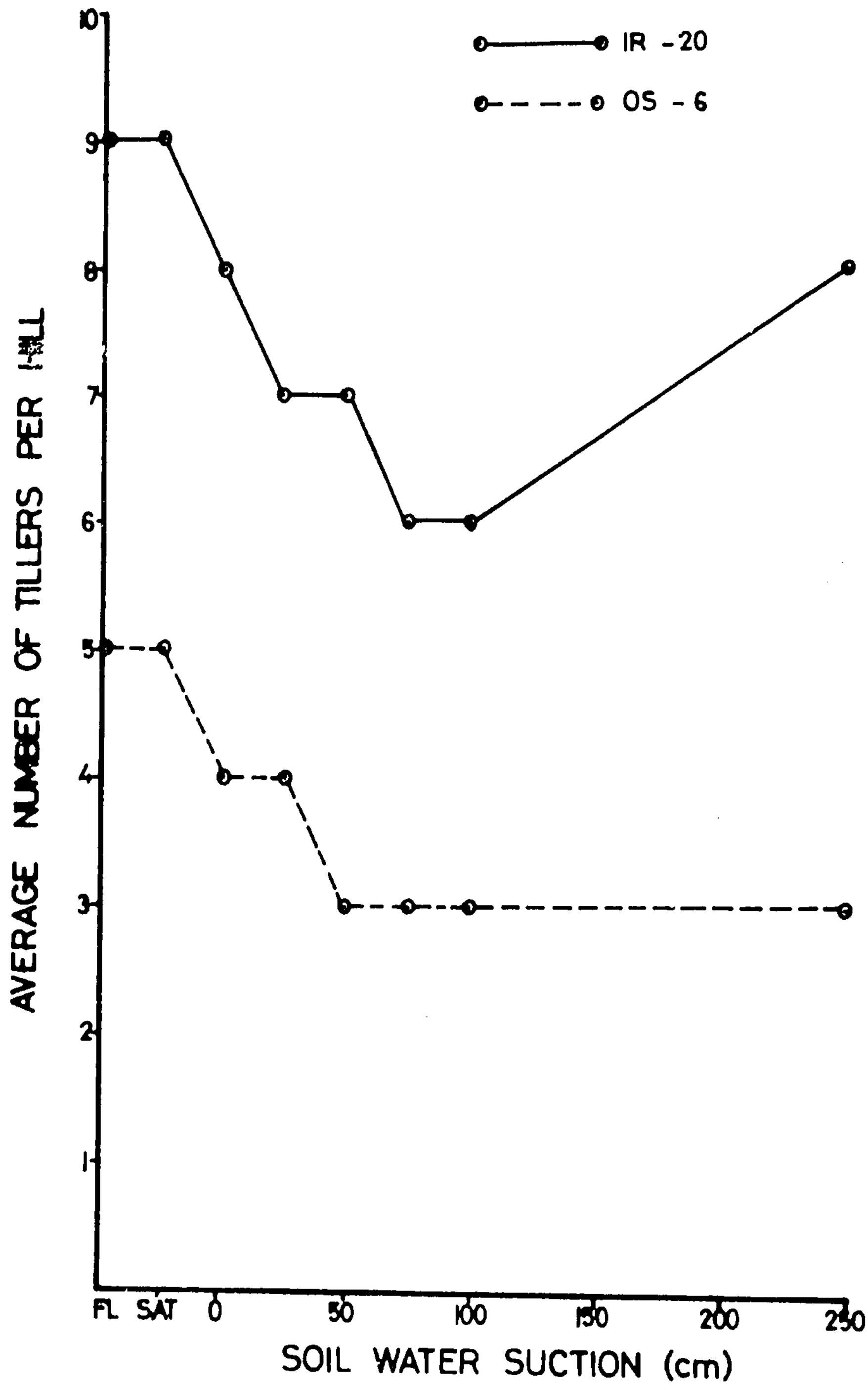

Fig. 10. Effect of soil moisture regime on number of tillers per hill.

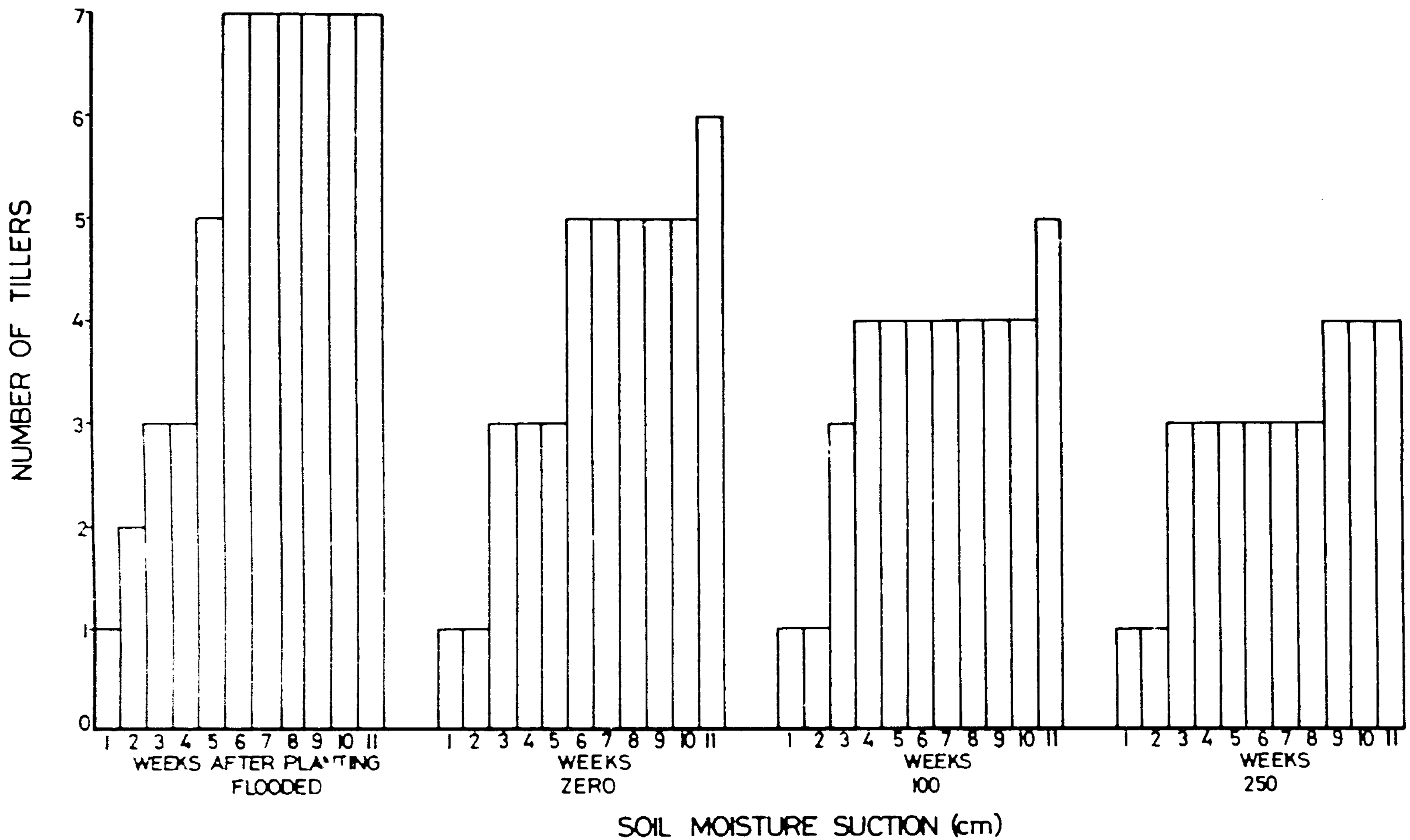

Fig.11. Effect of soil moisture regime on number of tillers produced at different growth stages in OS-6.

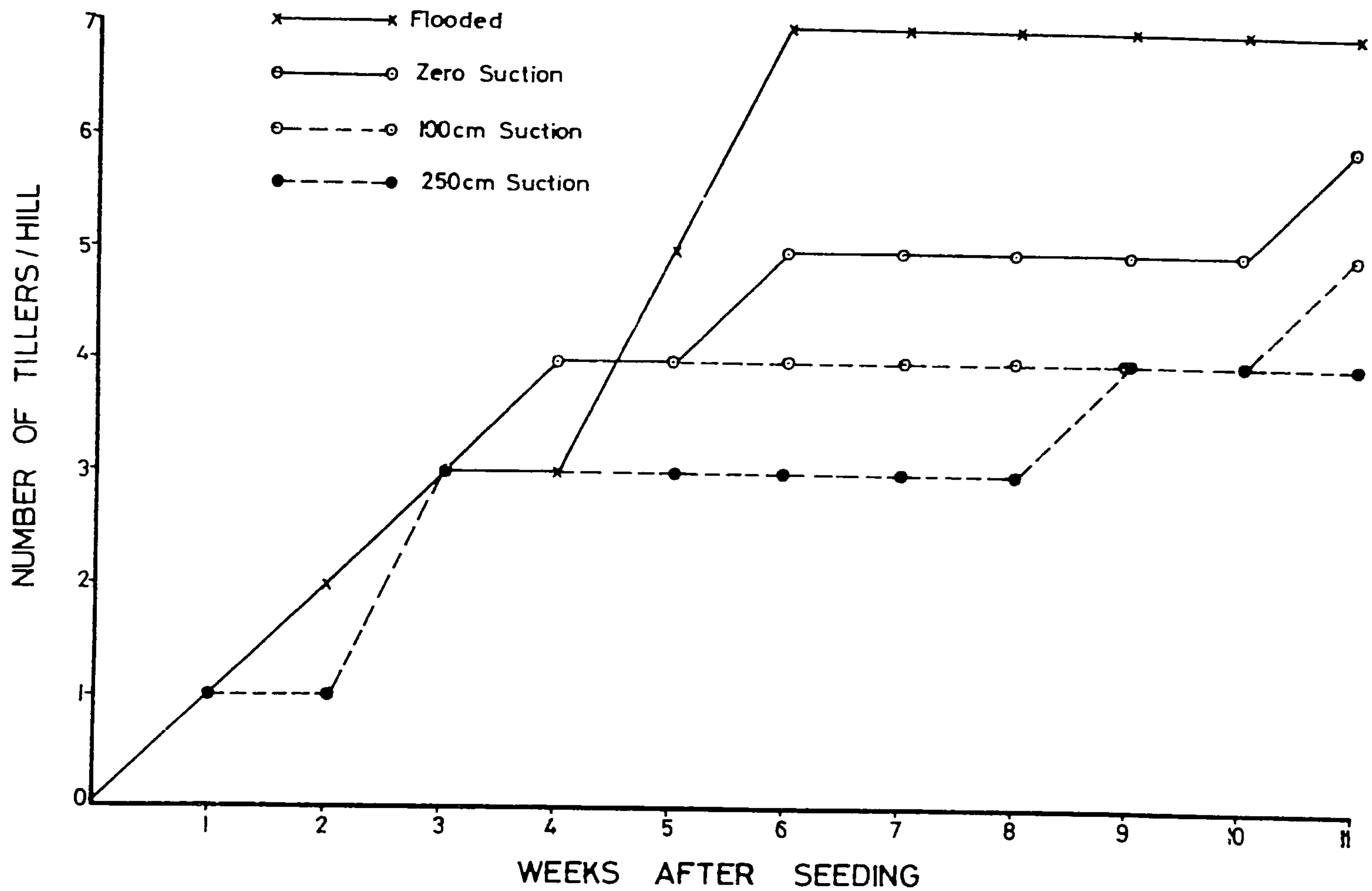

Fig.12. Effect of soil moisture regime on tiller production in OS-6.

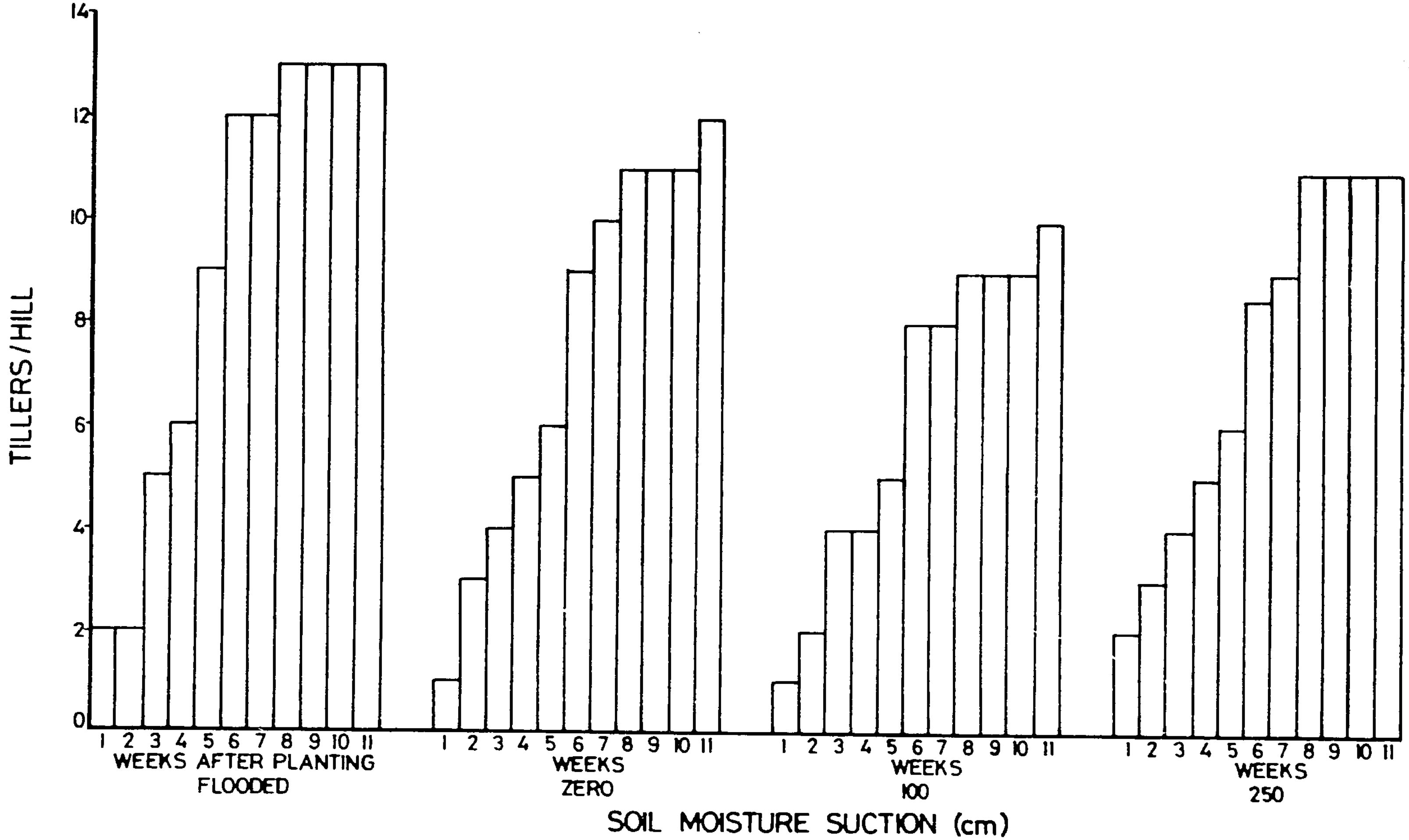

Fig.13. Effect of soil moisture regime on tiller production in IR-20.

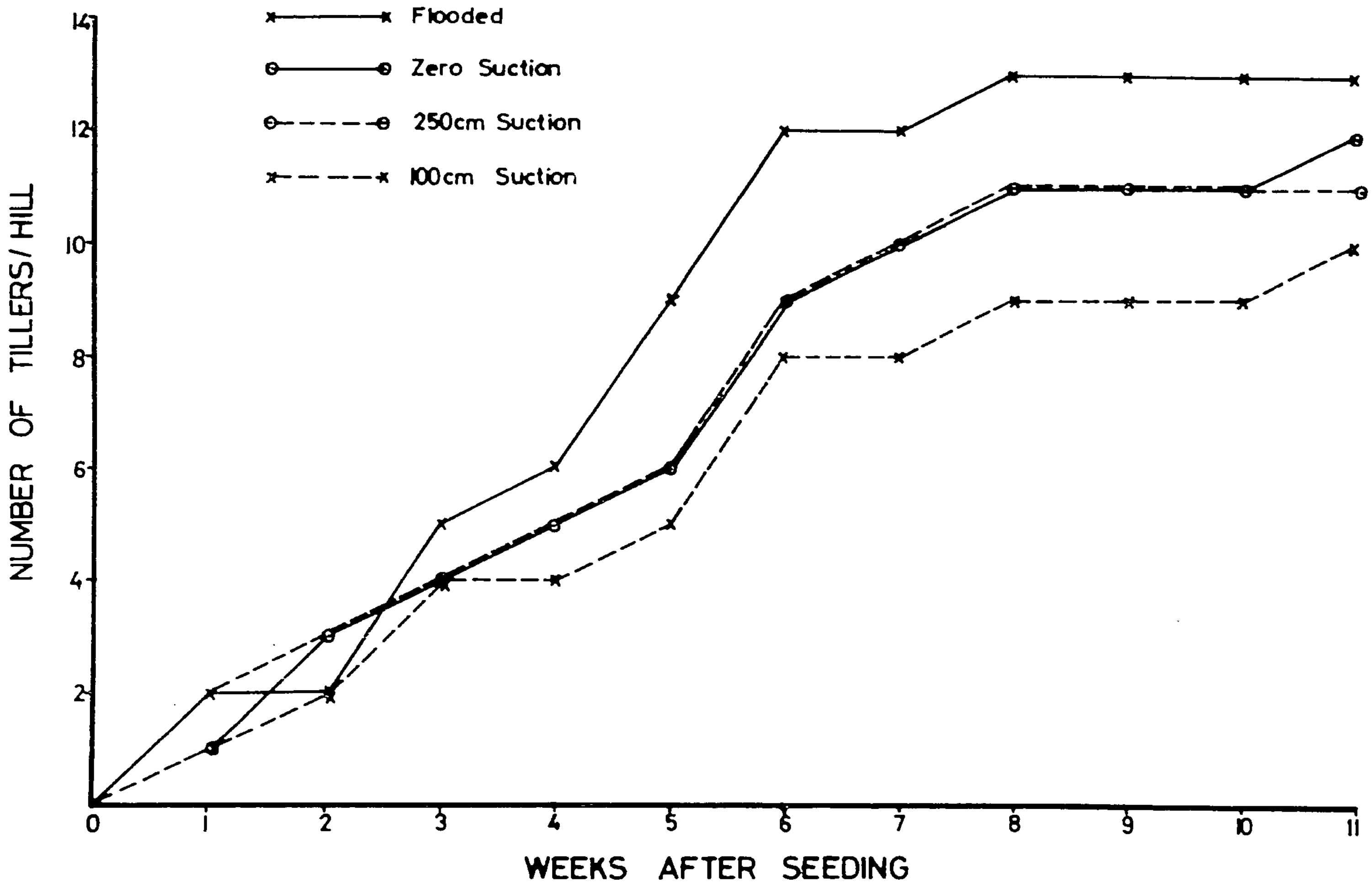

Fig.14 Effects of four soil moisture treatments on tiller production in IR-20 at different growth stages.

until the 11th week after planting. For the high suction treatment of 250 cm, unproductive tillers were even being produced during the reproductive phase of development. This was particularly true in the case of IR-20.

Days to heading and 50% flowering

Figures 15 and 16 show the effect of various levels of moisture stress on the number of days required for the heading and flowering of IR-20 and OS-6. In both cases the number of days had increased with increase in moisture stress. At a low moisture stress there was no significant difference in the effects of moisture regime, however, the effect was very significant at high moisture stress.

As for OS-6, there was a decrease in the number of days to heading with change in soil moisture regime from submergence to zero suction, followed by an increase in the days with increase in moisture stress. The overall increase in the days to heading for OS-6 was by 23 percent, with a maximum of 14 percent increase occurring as the moisture suction increased from 100 cm to 250 cm (Fig. 15). The response of IR-20 was slightly different from that of OS-6. There was a slight increase in the number of days to heading with change in soil moisture regime from submergence to zero suction, followed by a plateau in the curve between the suction ranges of zero and 50 cm, and then a sharp increase from 50 to 250-cm suction. The overall increase in the number of days to heading was only 9 percent, with a maximum of 4 percent within the suction range of 100-250 cm (Fig. 15).

The number of days to 50 percent flowering was affected, but slightly differently from days to heading. For both OS-6 and IR-20 there was a steady increase in the days to flowering with an increase in moisture stress. The relative increase in days to flowering with change in soil moisture regime from submergence to 250-cm suction was 21 and 24 percent, respectively for OS-6 and IR-20. The response curve of both varieties stayed parallel for all the moisture regimes (Fig. 16).

Dry matter production. The dry matter production at different stages of growth is shown in Figures 17-21 and Table 6. Both the moisture and varietal treatments had significant effects on the dry matter production at different stages of growth. There was also a significant correlation between dry matter production at different growth phases and the grain yield, and with total water use.

Data in Figure 17 show that OS-6 consistently produced more dry weight than IR-20 at all moisture regimes and for different growth stages. The differences in growth and dry matter production were parallel for all the moisture regimes, indicating no or little interaction between varietal

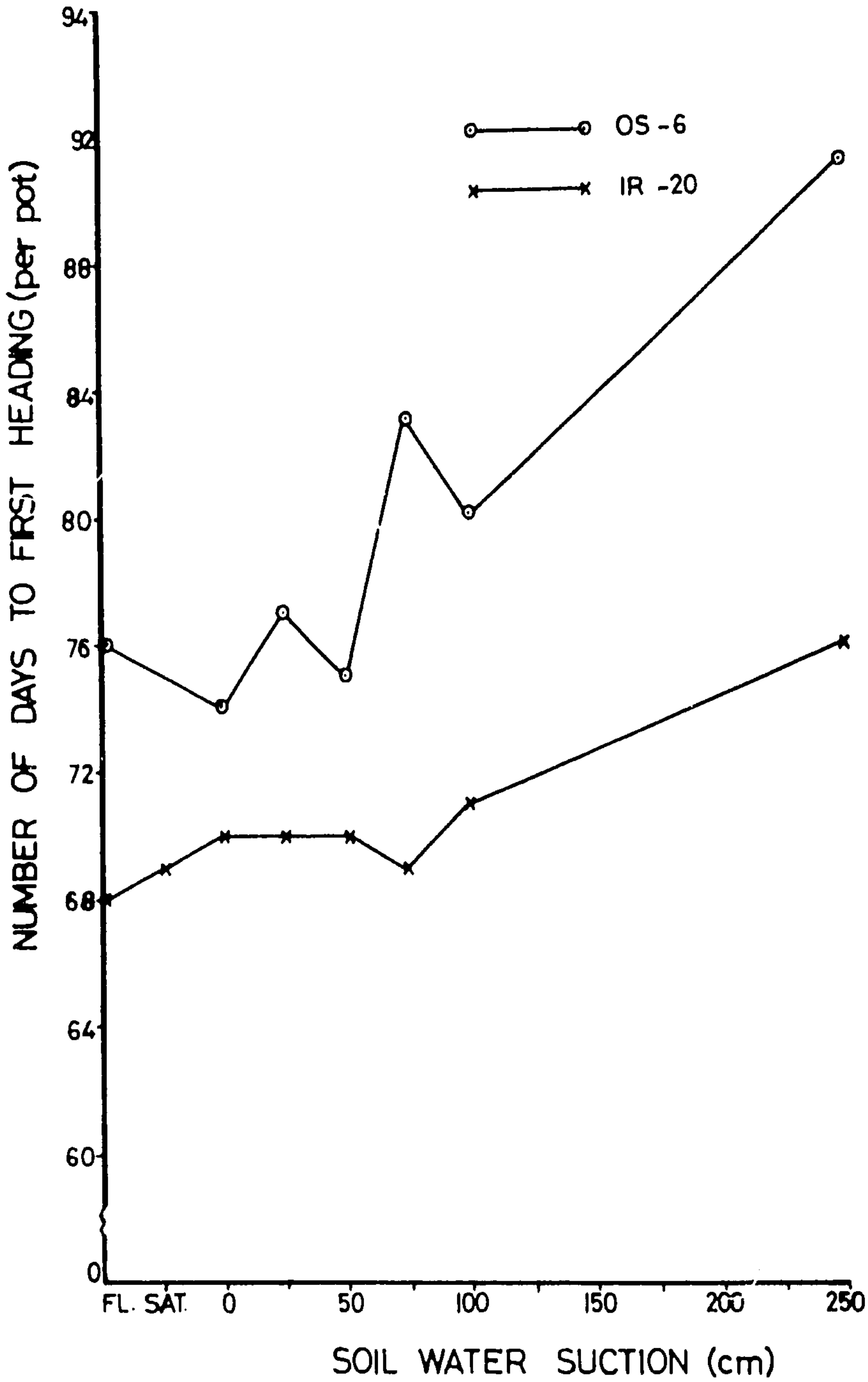

Fig.15. Effect of soil moisture regime on days to heading.

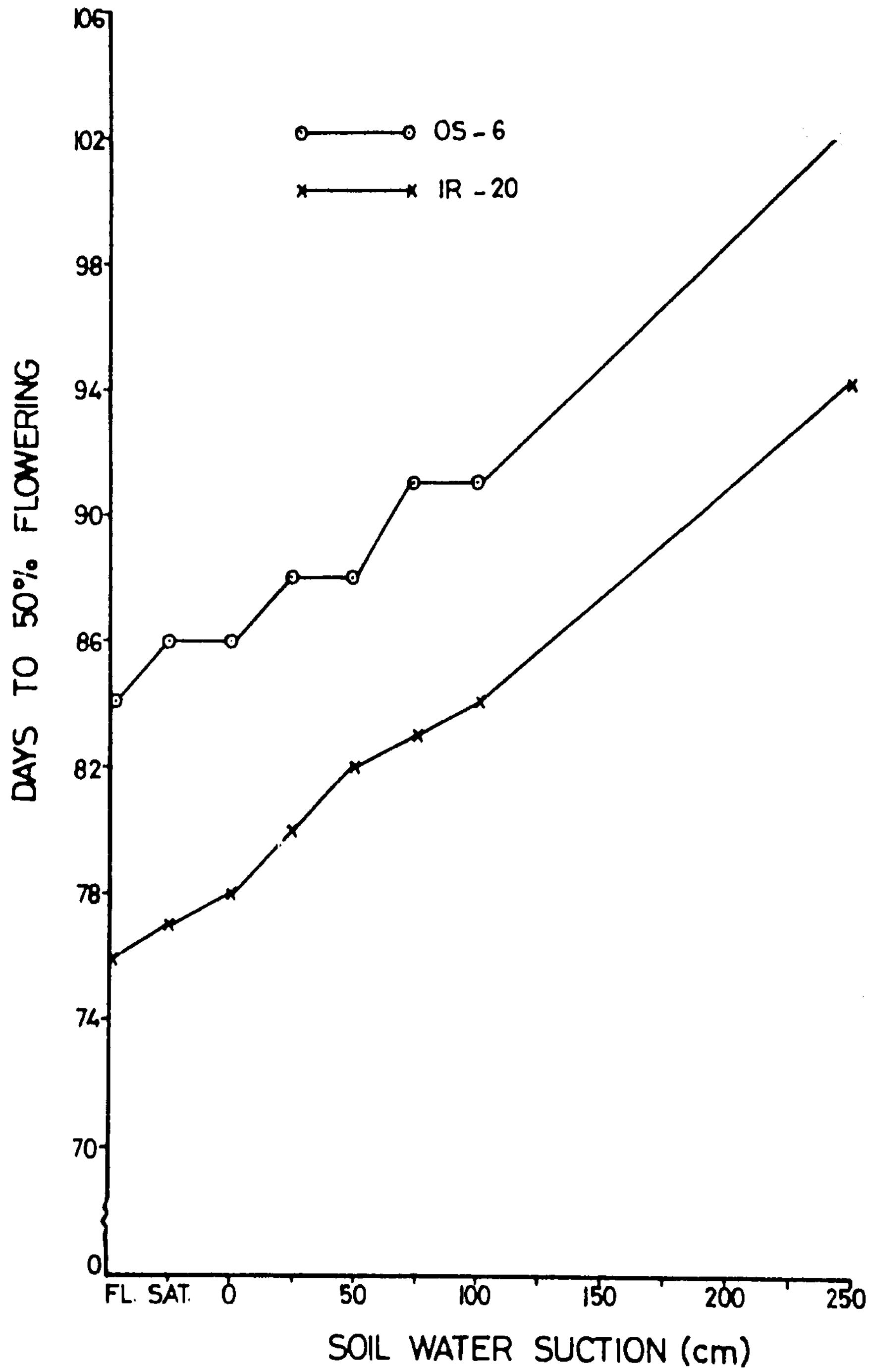

Fig.16. Effect of soil moisture regime on days to 50% flowering.

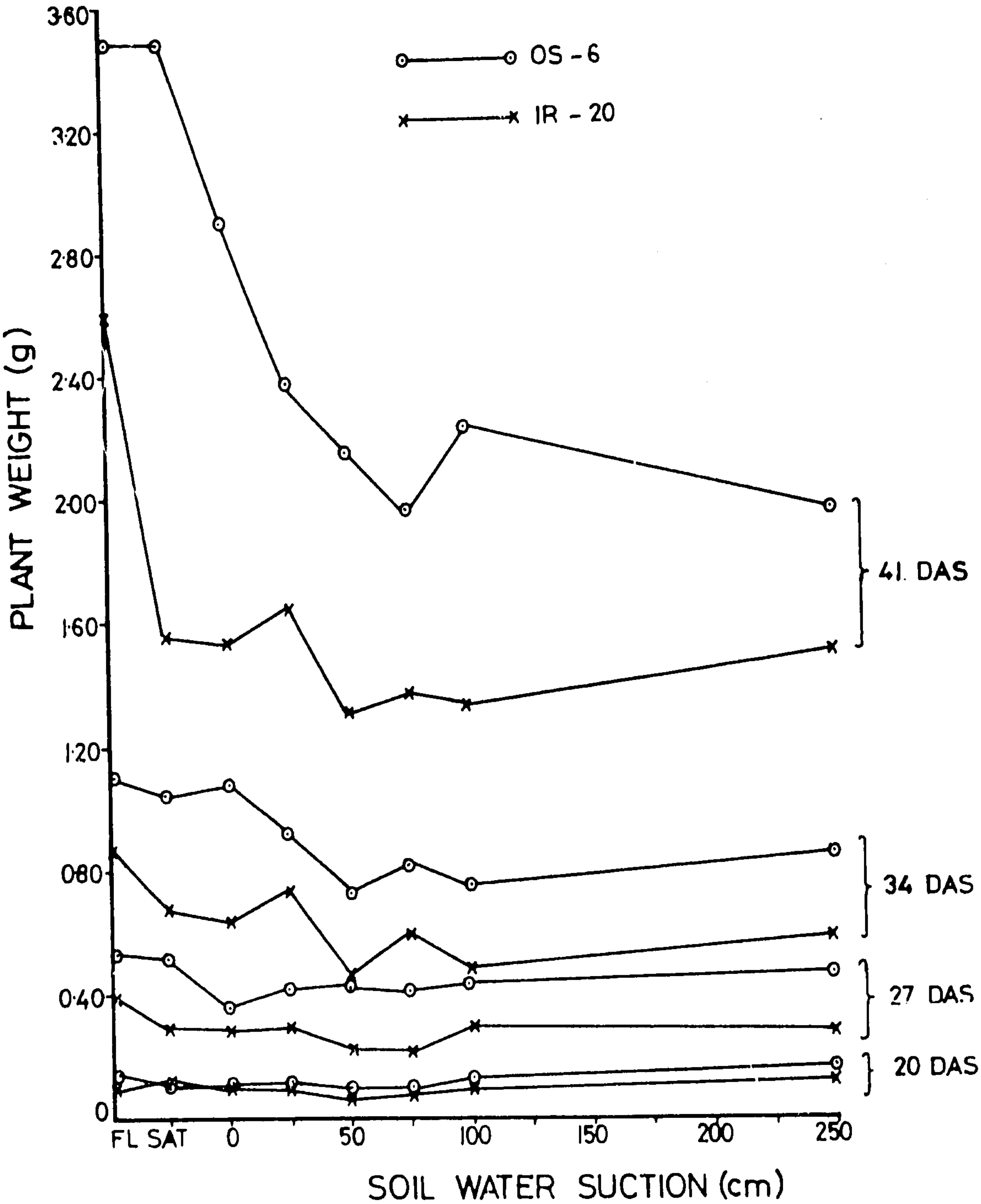

Fig.17. Effect of soil moisture regime on dry matter production on different days after seeding (DAS).

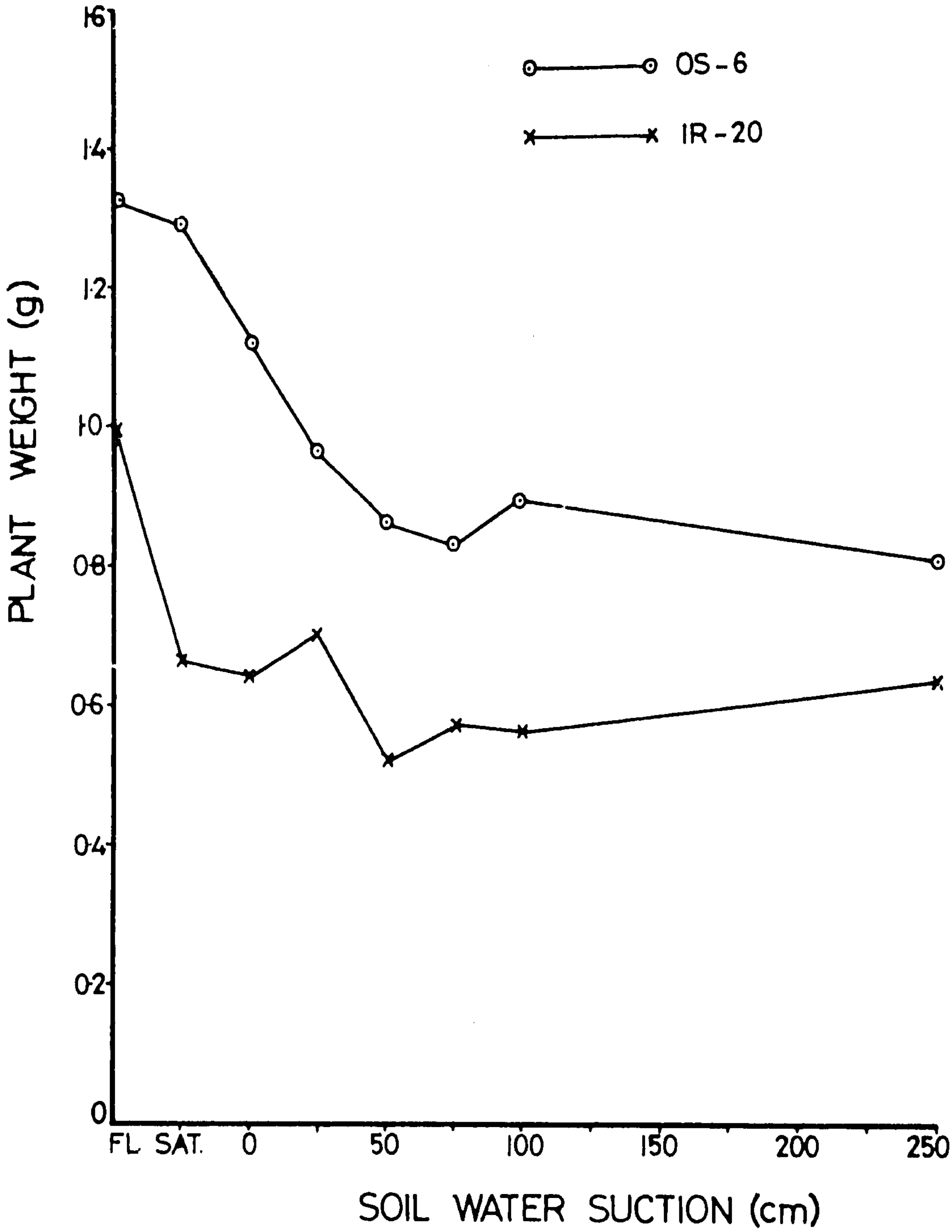

Fig.18. Effect of soil moisture regime on dry matter production 60 days after seeding.

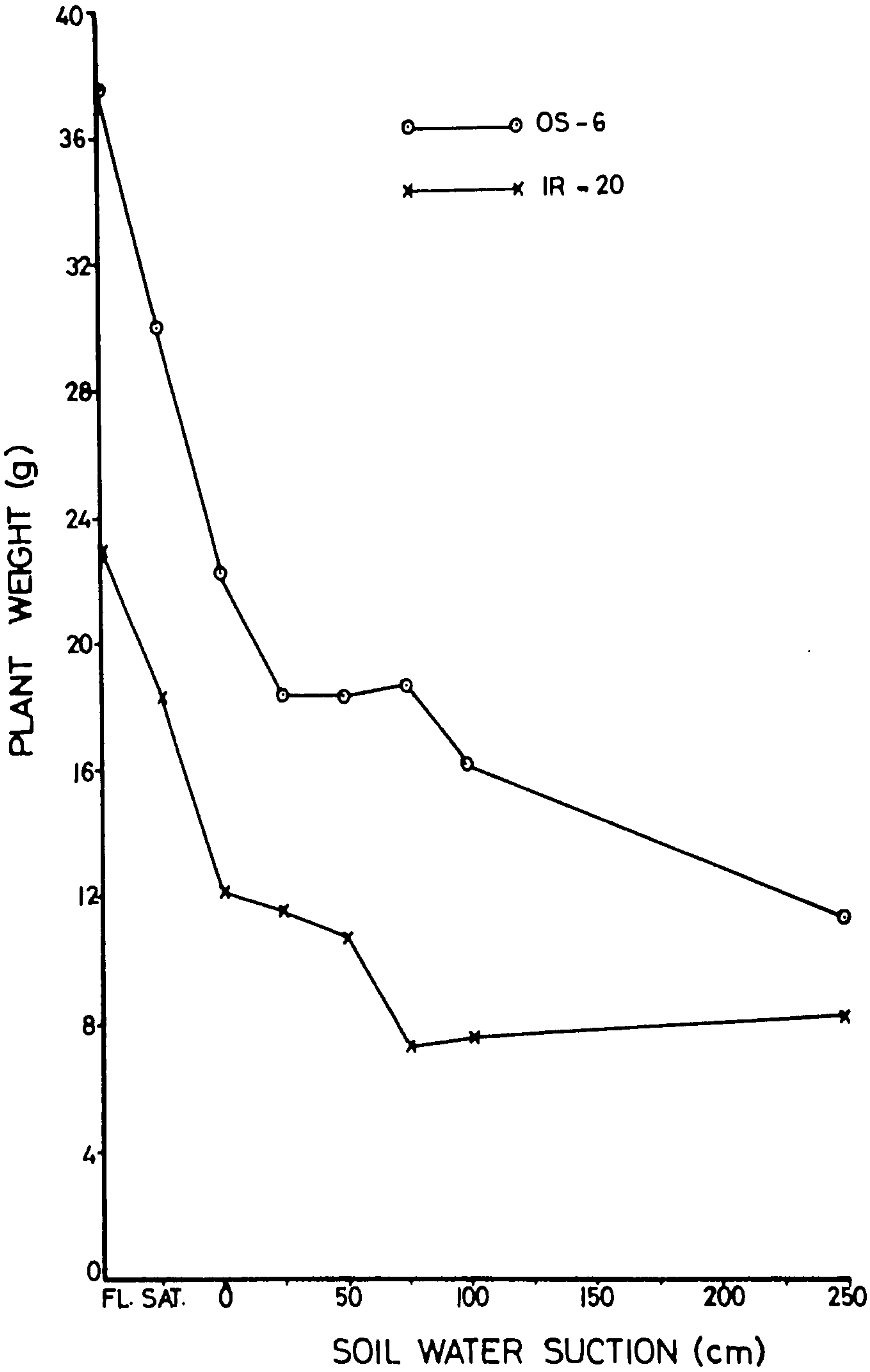

Fig.19. Effect of soil moisture regime on dry matter production 11C days after seeding.

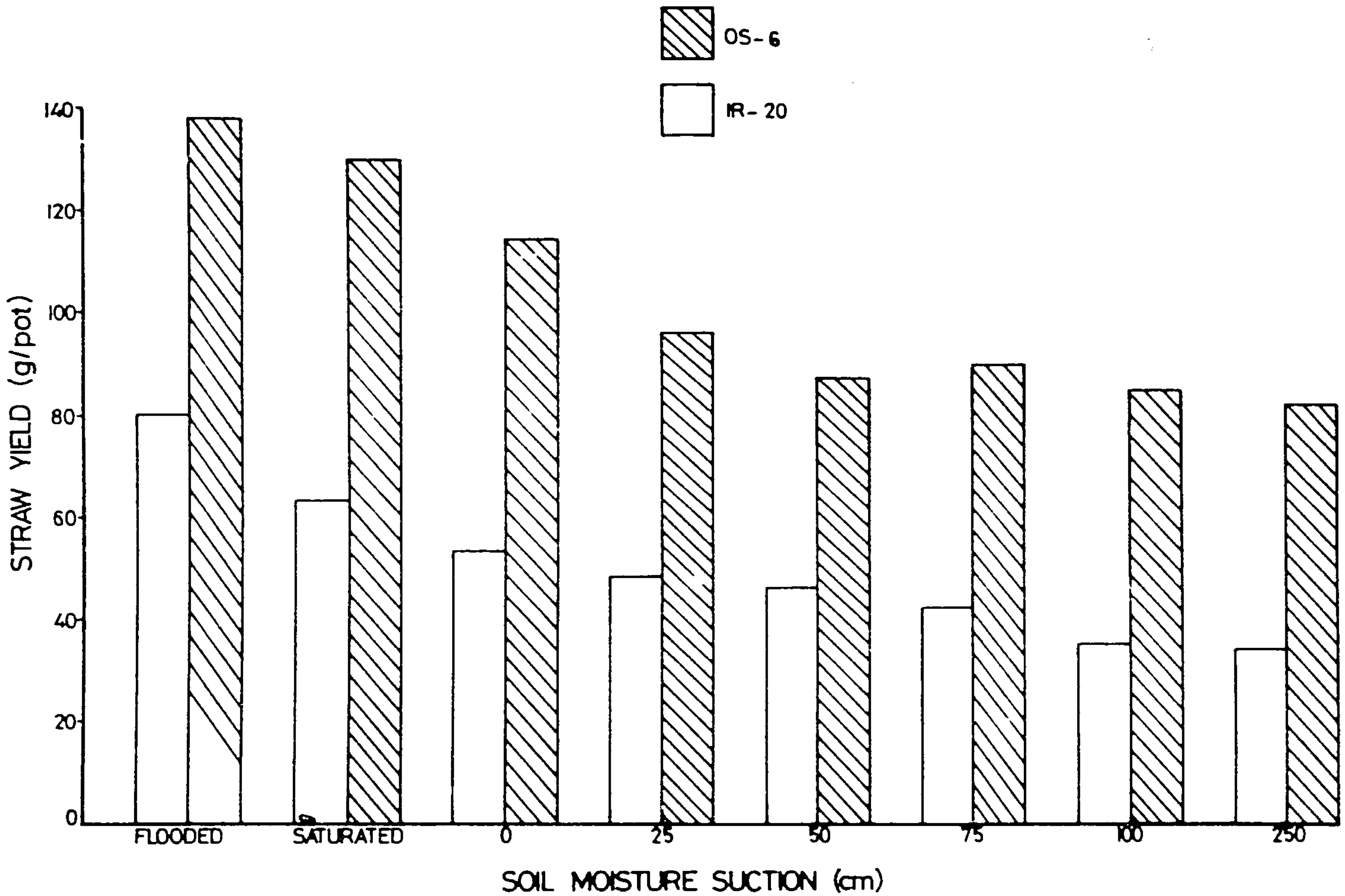

Fig.20. Straw yield of IR-20 and OS-6 as affected by the soil moisture regime.

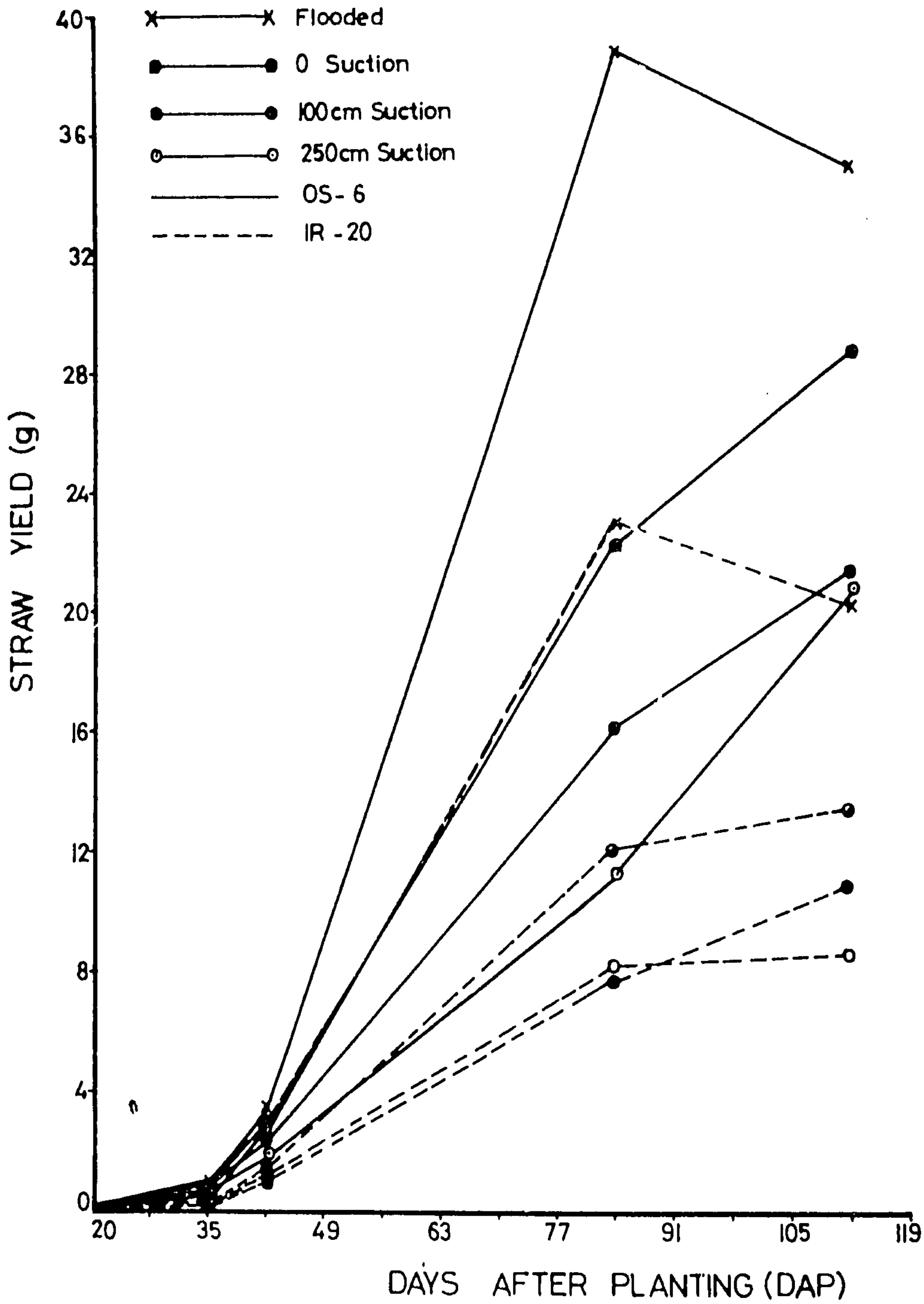

Fig.21. Effect of soil moisture regime on straw yield at different growth stages.

and moisture effects. But the differences in dry matter production of both varieties increased with increase in stage of crop growth.

Figure 18 shows the mean dry weight of IR-20 and OS-6 between the tiller initiation and maximum tillering stage, as affected by different soil moisture regimes. Although the dry matter production decreased with increase in stress for both IR-20 and OS-6, the initial rate of decline was greater in IR-20. For example, the rate of decline with change in moisture regime from submerged to saturated soil was 0.03 g/plant for OS-6 as compared with 0.3 g/plant for IR-20, 10 times decrease in IR-20 compared with OS-6. The overall decrease for the entire range of soil moisture suctions was 30 percent for both OS-6 and IR-20. Similar response was observed at the grain filling stage (Fig. 19). Whereas there was a decline in the dry matter production in OS-6 up to 250-cm suction, there was no change in the case of IR-20 beyond 75-cm of water suction. This may imply that the critical soil moisture potential for IR-20 is lower than that of OS-6.

The final straw yield of IR-20 and OS-6 at different soil moisture regimes is shown in Figures 20 and 21. Although OS-6 had higher straw yield than IR-20, there was no significant decrease in straw weight of OS-6 with increase in soil moisture stress from 25-250-cm suction. This plateau was reached in IR-20 at a soil moisture suction of 100 cm.

Figure 21 shows the changes in dry matter production in IR-20 and OS-6 during different growth stages and as influenced by various soil moisture regimes. It is interesting to observe, that in the case of both IR-20 and OS-6, the maximum vegetative growth rate was observed for the submerged treatment. But there was a definite decline in the straw weight of the submerged treatment from 12th week to maturity.

Plants under flooded and zero suctions have a consistently rapid growth rate during the vegetative growth period, with a sharp drop immediately after maturity, but those plants under zero and 100-cm suctions have a relatively smaller decrease after maturity.

Plants grown at 250-cm suction continue to increase their growth rate even after the plants in the other three treatments had reached maturity and growth had stopped completely. This shows that for plants under the high moisture stress the vegetative phase had lengthened considerably and growth had been unduly prolonged by water deficit.

Yield and components. Data in Figures 22-30 and Table 2 show the effect of moisture regime on the yield components of the OS-6 and IR-20. Figures 22 and 23 depict the grain yield of both varieties under different soil moisture regimes. OS-6 significantly outyielded IR-20, except at the highest soil moisture stress of 250 cm of water suction. Once again

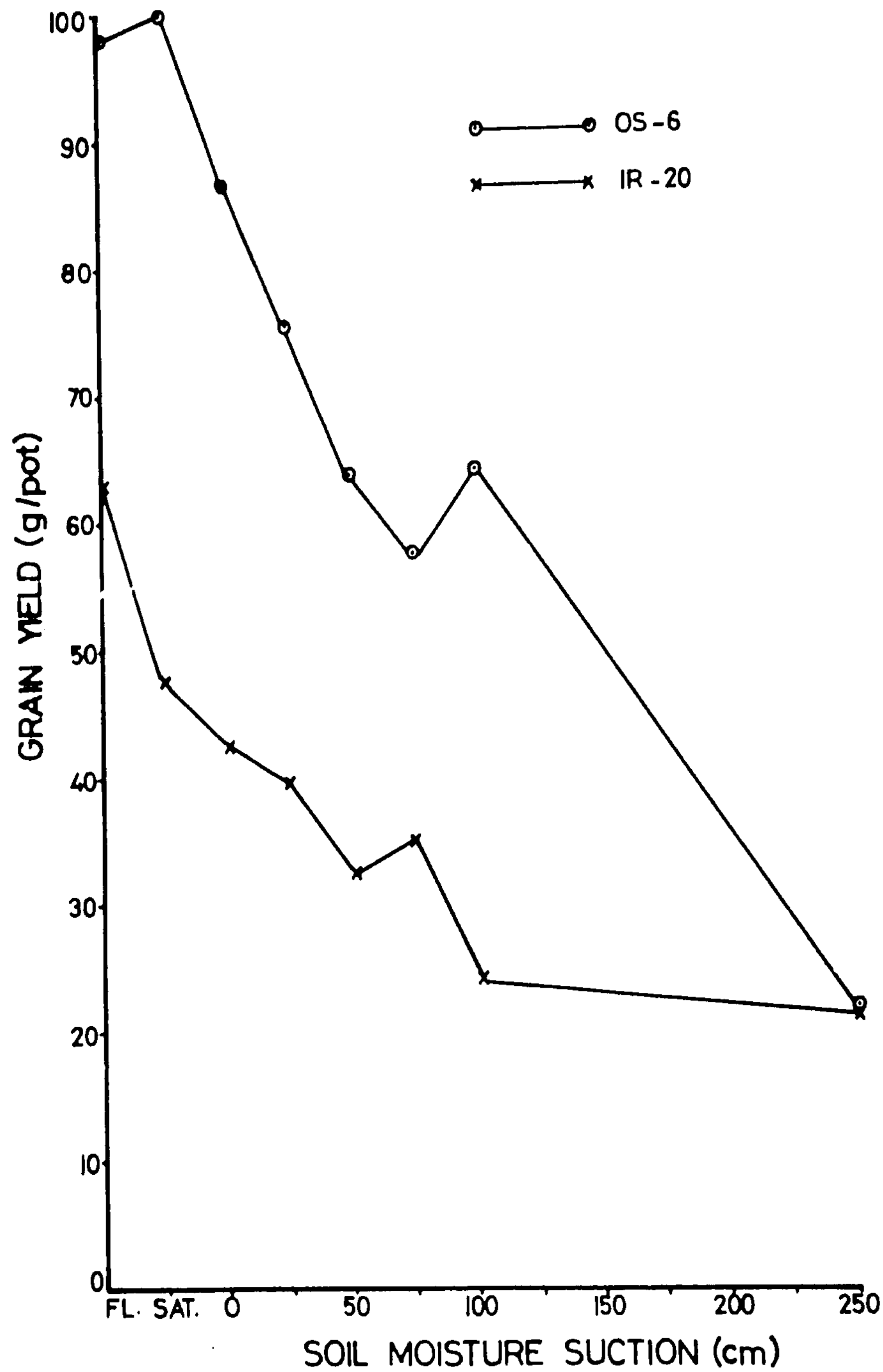

Fig.22. Effect of soil moisture regime on grain yield of IR-20 and OS-6.

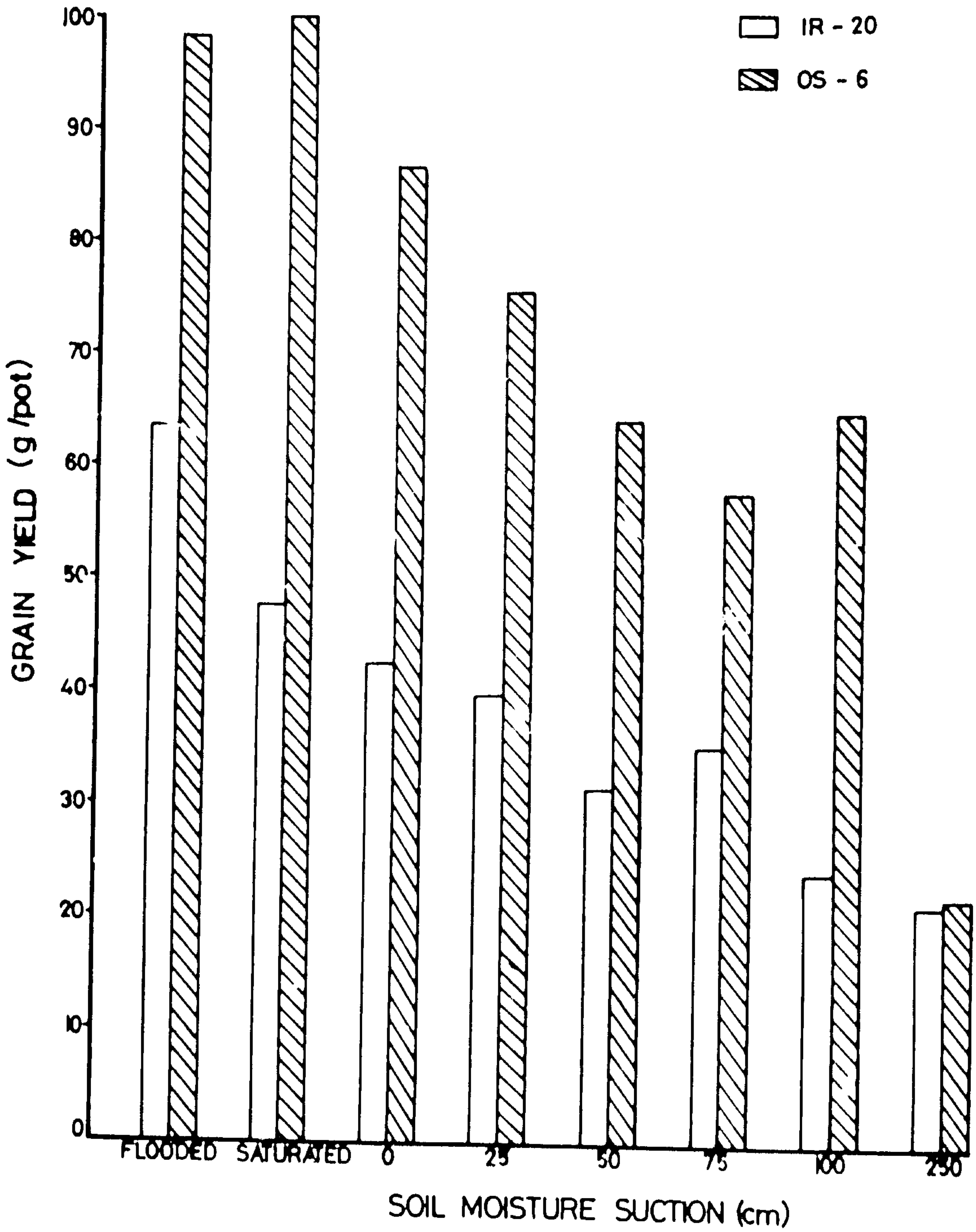

Fig.23. Grain yield of IR-20 and OS-6 for different soil moisture regimes.

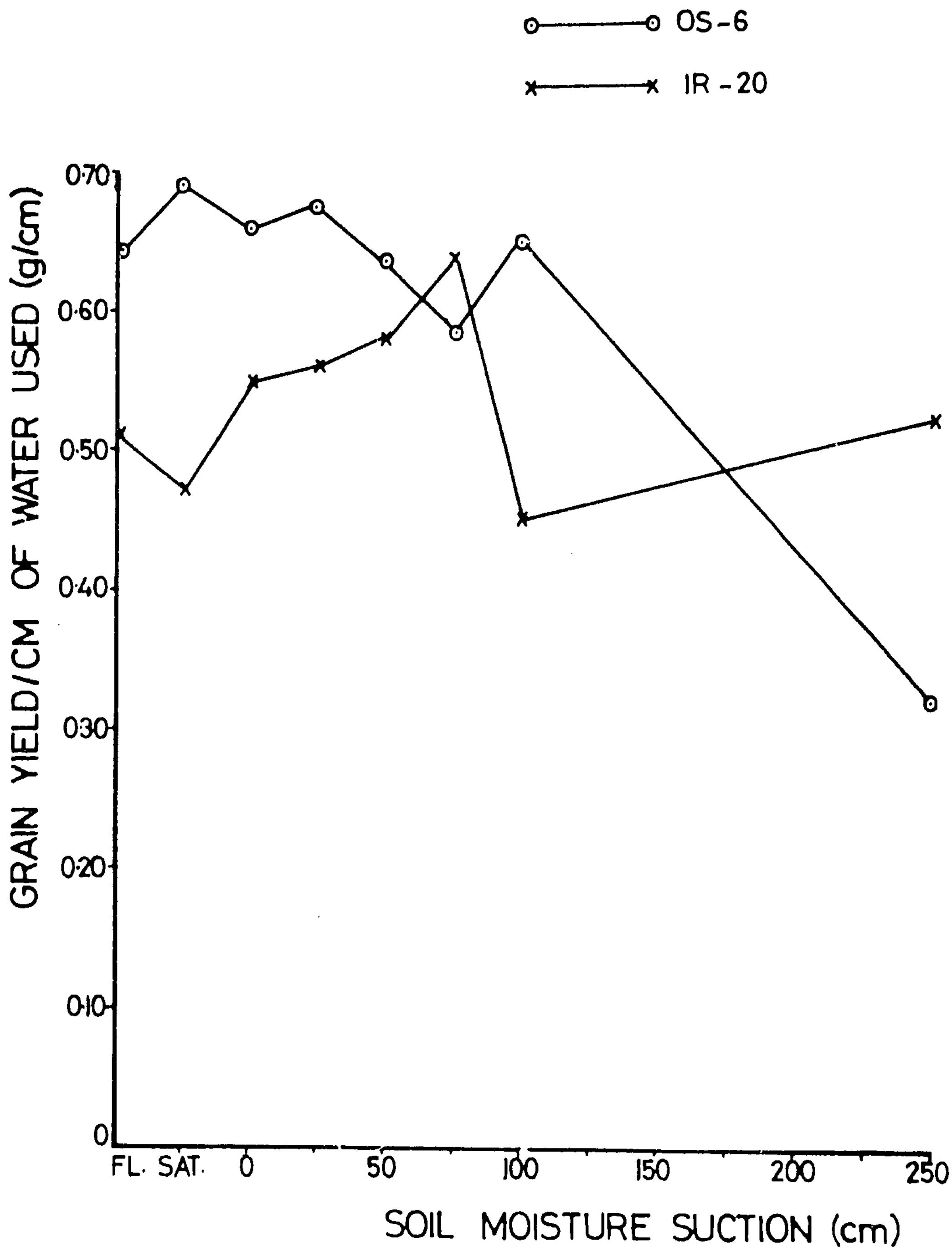

Fig.24. Grain yield: water use ratio for different soil moisture regimes.

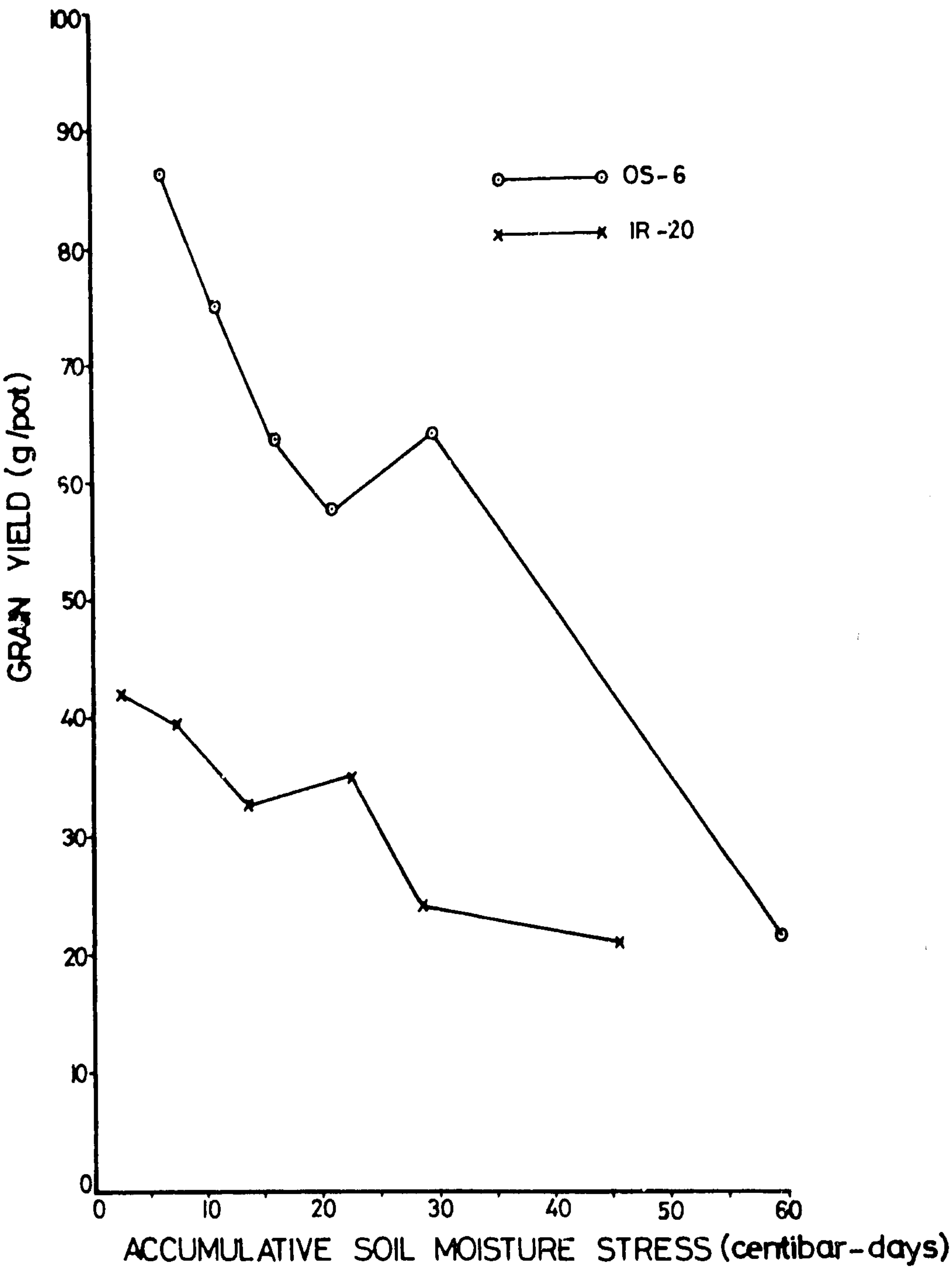

Fig.25 Effect of accumulative soil moisture stress on grain yield.

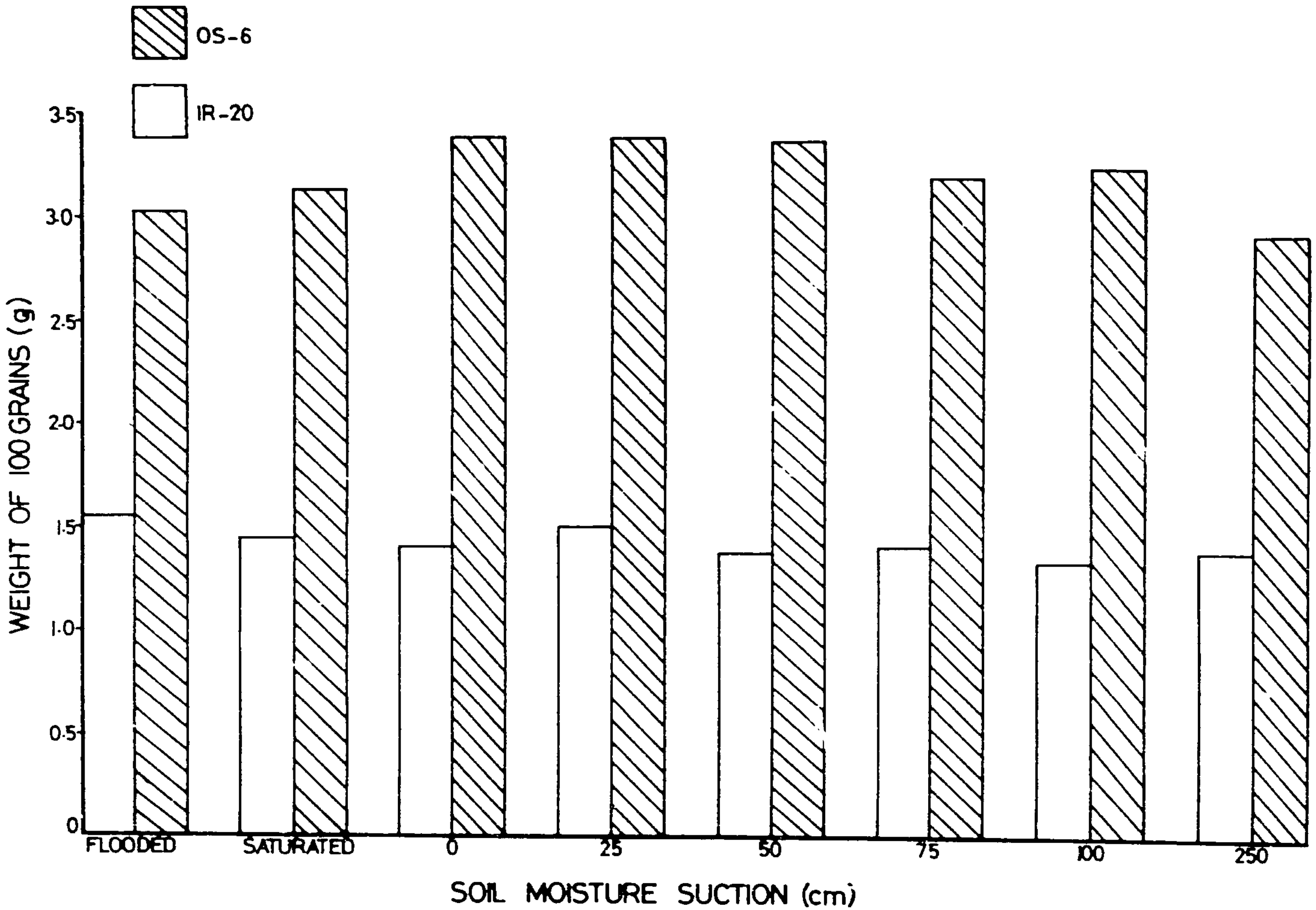

Fig.26 Effect of soil moisture regime on 100-grain weight.

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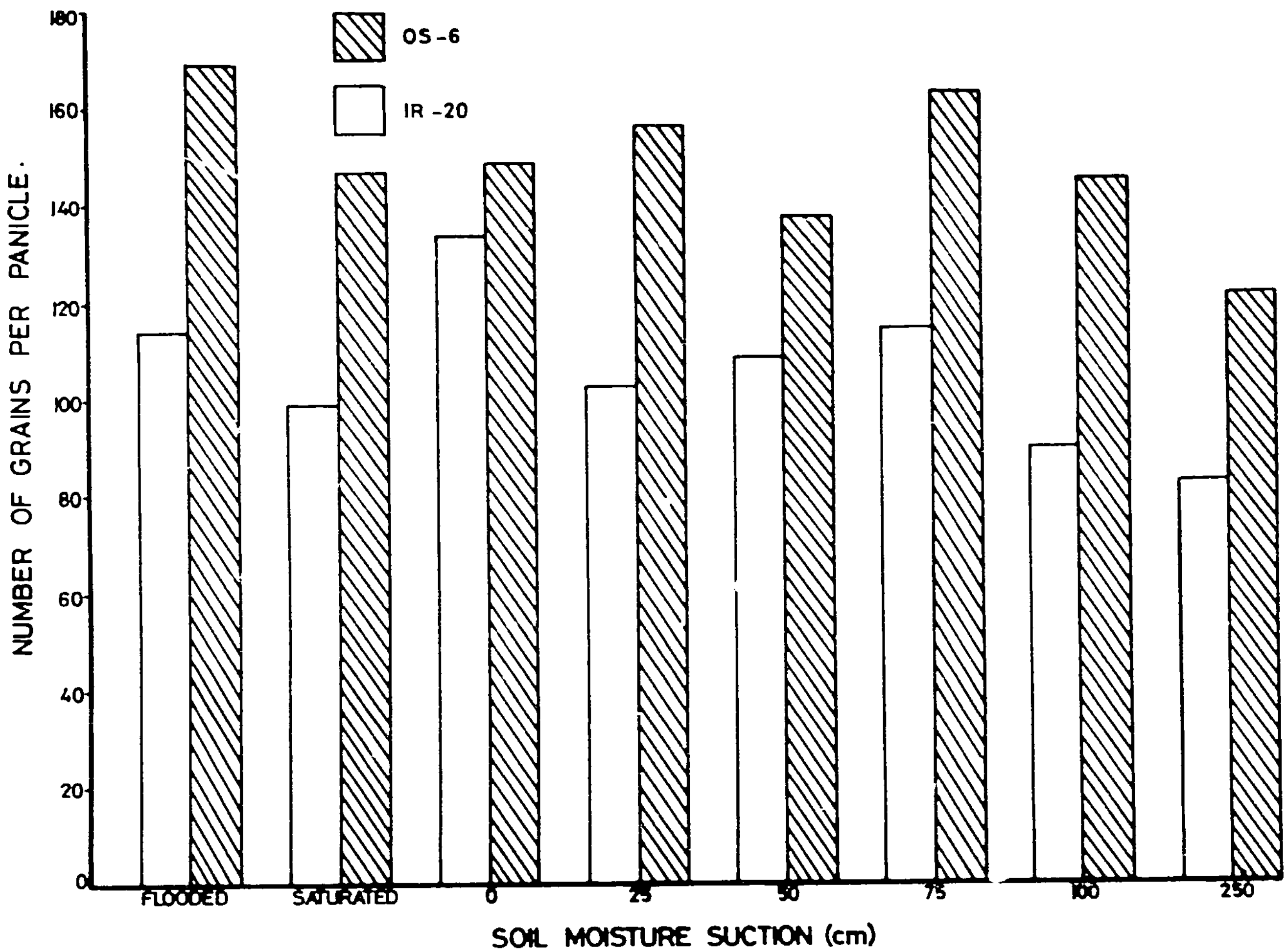

Fig.27 Number of grains per panicle as affected by the soil moisture regime.

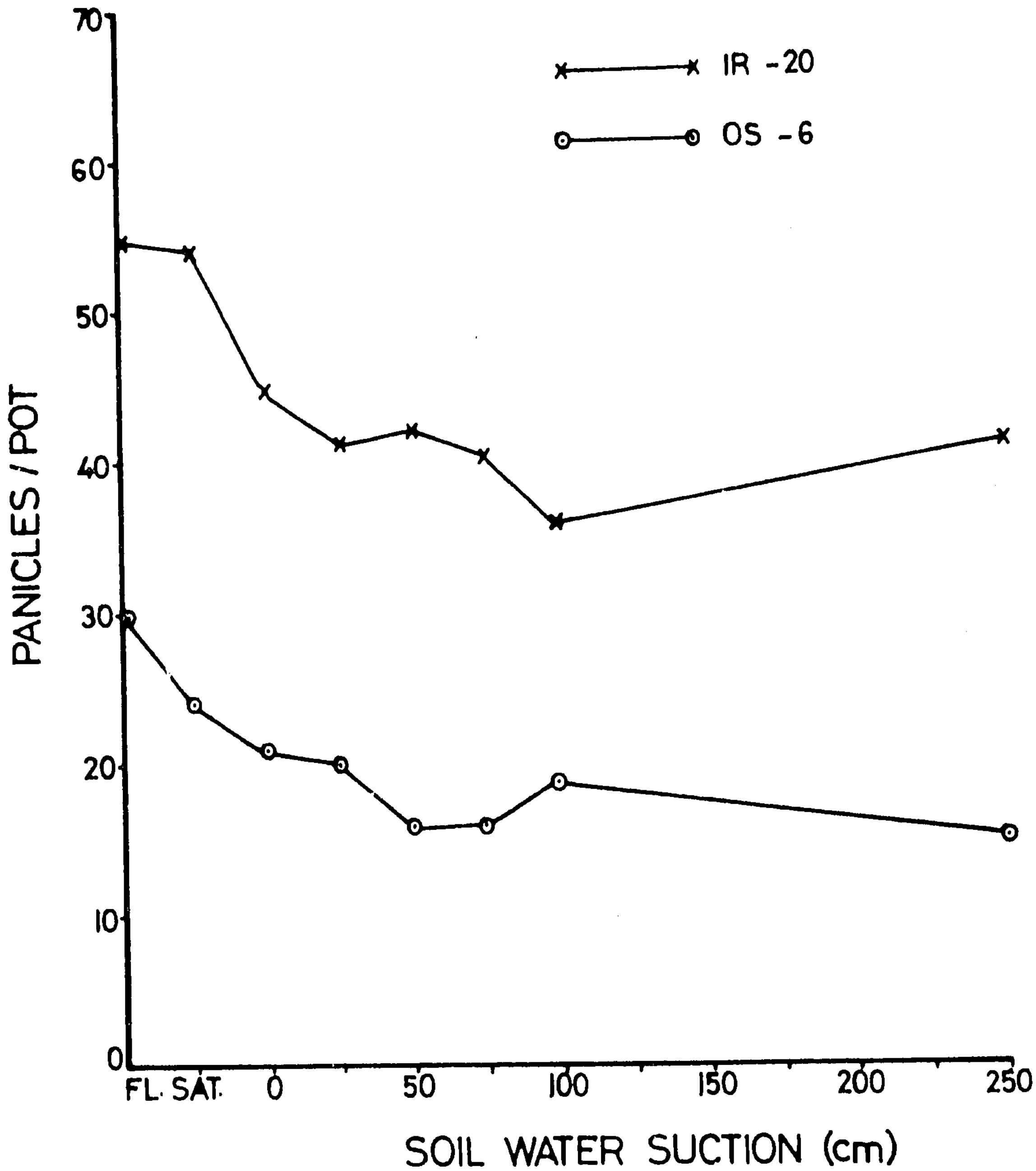

Fig.28 Effect of soil moisture regime on productive panicles.

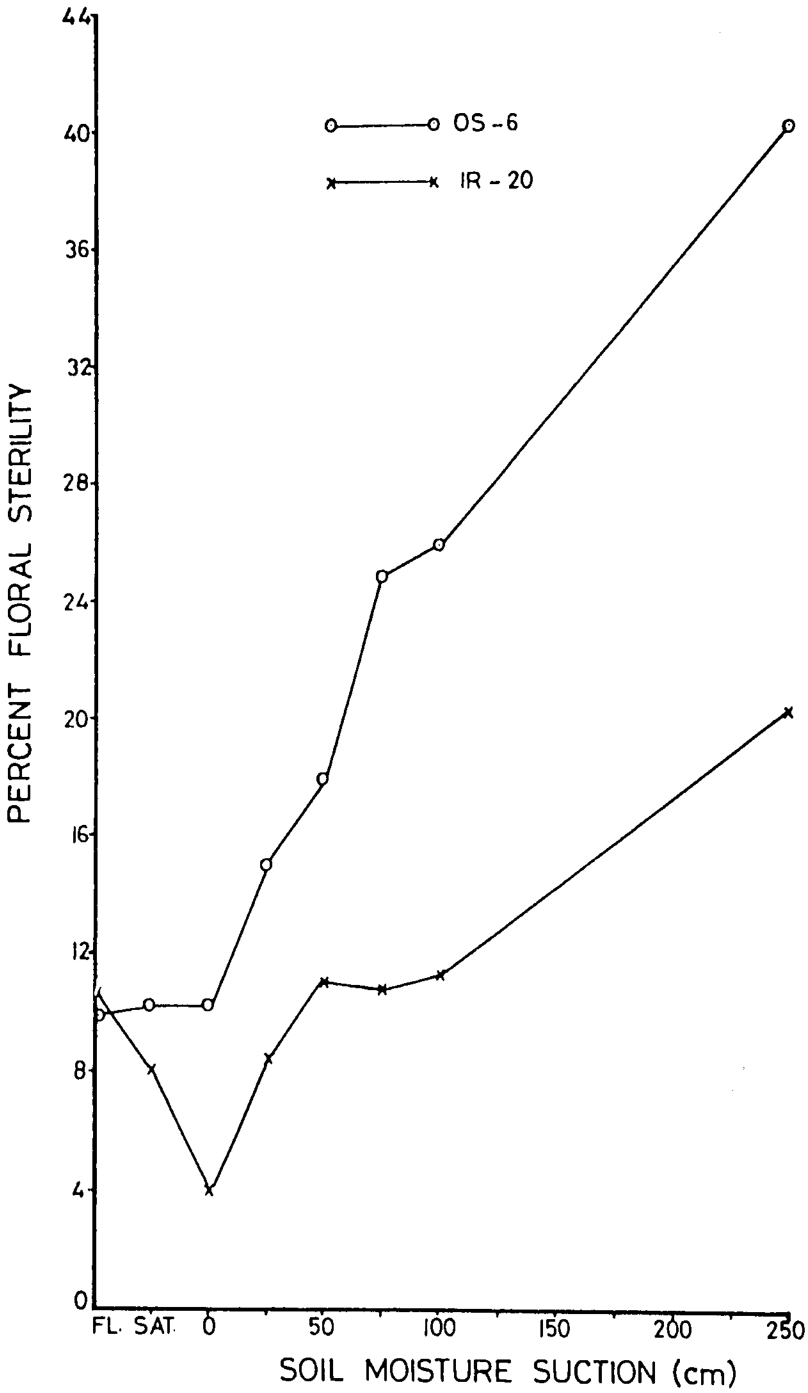

Fig.29 Effect of soil moisture stress on floral sterility.

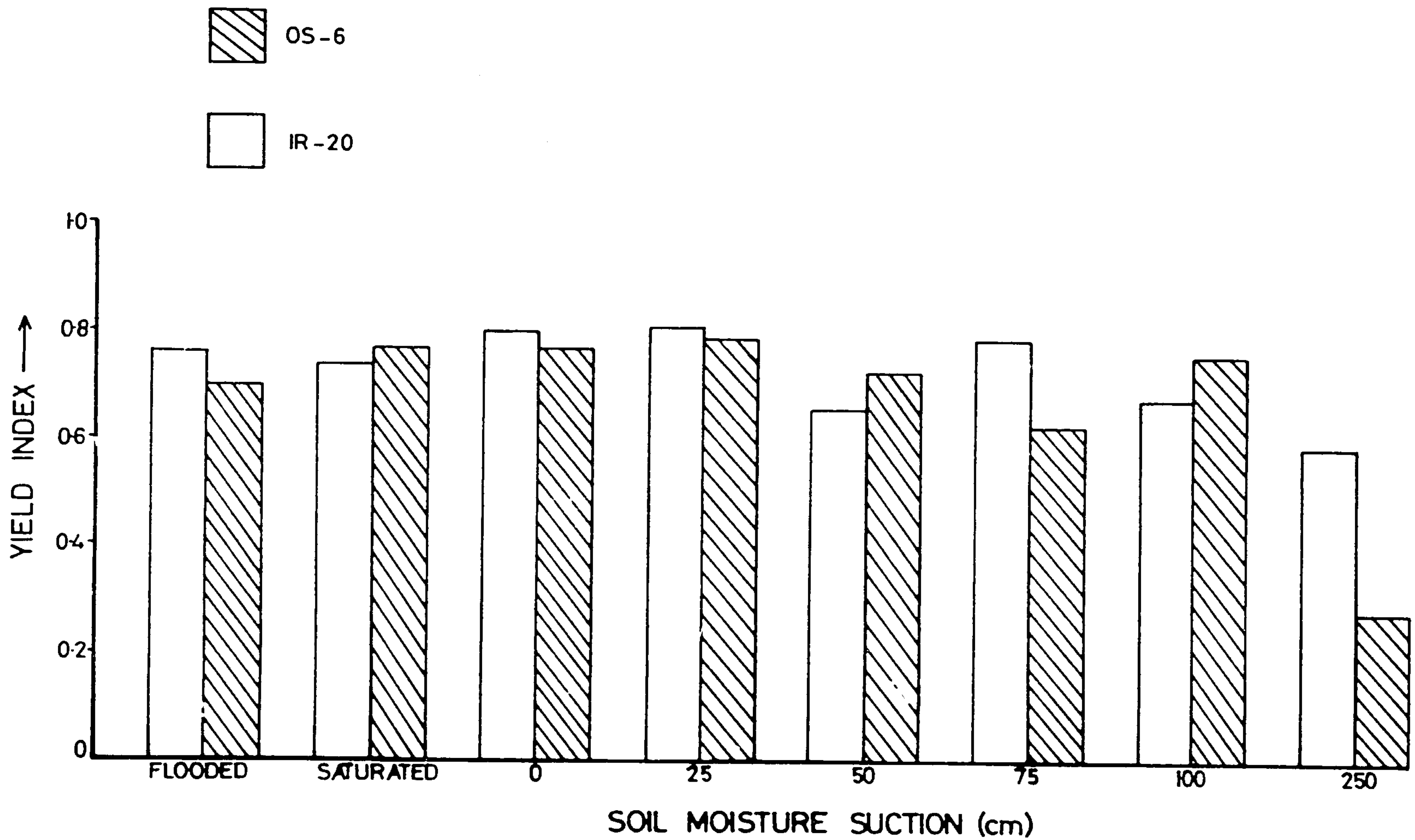

Fig.30. Grain: Straw ratio for different soil moisture regimes.

there was a small increase in the grain yield of OS-6 with a change in moisture regime from submergence to saturation without submergence. The percent increase in the grain yield of OS-6 over IR-20 was 55, 110, 105, 90, 96, 64, 168, 2 percent for soil moisture regimes of submergence, saturated soil, zero suction, 25 cm, 50 cm, 75 cm, 100 cm and 250 cm of moisture suction. It is interesting to observe that the maximum difference in the yield of IR-20 and OS-6 (168%) occurred at a soil moisture stress of 100 cm suction. Obviously, for this sandy soil, suction of 250 cm is equally detrimental (lethal) for both varieties.

Figure 24 shows the grain yield per cm of water used. From flooded treatment to about 100-cm suction, OS-6 had consistently higher yield per cm of water. There was a slight increase in the WUE of IR-20, for suction ranging from 0 to 75 cm, because the LAI and the water required to maintain desired suction decreased. However, there was a sharp decrease in the WUE of IR-20 with increase in suction to 100 cm. The WUE of OS-6 did not change over the range of submergence, zero suction up to 100 cm of suction. The grain yield in 250-cm suction was practically zero in both varieties; hence, the WUE at that suction is also zero or of little practical significance.

It is interesting to compare grain yield of IR-20 and OS-6 as a function of the cumulative soil moisture stress (Fig. 25). OS-6 had higher grain yield than IR-20 for all the stress ranges. In a way, IR-20 did not have the same level of cumulative stress as OS-6 at a given soil moisture regime. OS-6 is definitely a superior variety for upland or harsh moisture regimes. The relative yield of IR-20 compared with OS-6 at cumulative soil moisture stress of 10, 20, 30, 40, 50-meter-days was, respectively, 0.48, 0.59, 0.38, 0.46, and 0.57.

The analysis of the yield components gives interesting information as to the source of high yield of OS-6 compared with IR-20. The unit grain weight of OS-6 was definitely superior to that of IR-20 at all the moisture regimes. Whereas the unit grain weight of IR-20 decreased with increase in moisture stress, there was a slight increase in the unit grain weight of OS-6 between the suction range of submergence and 100 cm. Perhaps molding of grains and other fungal incidence on OS-6 during submergence had adversely affected unit grain weight. The unit grain weight of OS-6 declined significantly only at the highest drought stress of 250-cm suction.

Number of grains/panicle was also more in OS-6 than IR-20 for all the moisture regimes investigated (Fig. 27). The OS-6 had more grain count/panicle than IR-20 by 48, 49, 11, 52, 27, 43, 61, and 47 percent, respectively at soil moisture regimes of submergence, saturated soil, and suction of 0, 25, 50, 75, 100 and 250 cm. The significant decrease in the number of grains/panicle in OS-6 occurred only at soil moisture regime of 250-cm suction (Table 4).

Table 3. Straw yield, plant growth and dry matter production under different levels of soil moisture stress.

Soil moisture regime	Straw yield g/pot		Straw yield mid tillering g/plant		Straw yield at grain filling g/plant		Height at flowering (cm)		Height at harvest (cm)		Days to heading		Days to 50% flowering	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	80.7	138	2.60	2.95	23.1	37.6	105	161	77.3	183	67	76	76	84
Saturated	62.8	130	1.55	3.48	18.3	31.6	96.8	155	73.3	181	69	75	77	86
0-cm suction	53.2	114	1.53	2.91	12.1	22.2	91.8	155	73.8	174	70	74	79	86
25-cm suction	48.6	95.5	1.64	2.37	11.5	18.3	90.3	154	76.0	171	70	77	80	89
50-cm suction	46.2	86.8	1.30	2.15	10.6	18.3	84.5	154	71.3	173	70	75	82	89
75-cm suction	42.2	89.7	1.37	1.96	7.3	18.6	83.0	149	71.0	170	69	83	83	91
100-cm suction	35.1	84.4	1.33	2.23	7.7	16.1	84.3	146	70.8	163	80	84	84	91
250-cm suction	34.3	82.7	1.50	1.95	8.2	11.3	84.0	136	68.8	156	91	92	92	100
LSD (.05)	9.1		0.31		2.7		3.8		3.8		2		2	
LSD (.05)	12.1		0.42		3.6		5.1		5.0		2		2	
CV (%)	23.6		30.2		31.8		6.3		6.1		4.4		3.6	

Table 4. Influence of soil moisture stress on yield and yield components of IR-20 and OS-6.

Soil moisture regime Soil moisture regime	Grain yield g/pot		Grains/panicle		Panicles/pot (kg)		Unit grain weight g/100		Number of sterile grains/pot		Number of sterile grain per panicle		Total water use (cm)		Number of tiller/plant	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	63.3	98.1	114	169	0.40	0.82	1.55	3.02	319	146	18	17	121	153	13	7
Saturated soil	47.6	100.0	99	147	0.33	0.67	1.44	3.12	137	112	9	14	97	141	13	6
Zero suction	42.4	86.8	134	149	0.45	0.83	1.40	3.38	65	102	6	16	77	129	12	6
25-cm suction	39.6	75.4	103	157	0.35	0.78	1.50	3.38	110	121	9	20	69	109	10	5
50-cm suction	32.4	63.4	109	138	0.41	0.76	1.37	3.34	144	100	12	20	57	98	11	4
75-cm suction	35.1	57.4	115	164	0.47	0.73	1.40	3.29	155	221	13	43	54	96	10	5
100-cm suction	24.1	64.5	90	145	0.33	0.86	1.33	3.34	97	149	10	32	47	97	10	5
250-cm suction	21.3	21.7	83	122	0.29	0.69	1.38	2.92	195	347	17	62	39	63	11	4
LSD (.05)	9.4		15		0.04		0.07		70		7		9		1	
LSD (.05)	12.4		21		0.06		0.10		93		9		12		1.5	
CV (%)	34.4		23.9		14.7		6.33		88.2		72		20		27	

Although the number of panicles/pot at harvest was more in IR-20 than in OS-6, most of these panicles were empty and unproductive (Fig. 28). Consequently the total weight of panicles per pot in OS-6 was significantly greater than IR-20 for all the soil moisture regimes investigated (Table 4). The relative panicle weight per pot in IR-20 compared with OS-6 was respectively, 0.49, 0.49, 0.54, 0.45, 0.54, 0.64, 0.38, and 0.42 for the moisture regimes listed in the increasing order of soil moisture stress.

Total number of sterile grains per pot did not follow a definite pattern in both varieties in relation to soil moisture stress (Table 4). However, the percentage of sterile grains in OS-6 was more than that of IR-20, particularly toward high soil moisture stress. Because grain yield of OS-6 is significantly higher than that of IR-20, despite the fact that floral sterility in OS-6 was also high, this may imply that the maximum yield potential of OS-6 under drought stress is significantly greater than that of IR-20. There is a considerable scope for yield improvements in OS-6 both in terms of genetic manipulations and in soil and water management.

The influence of soil moisture regimes on the yield index of IR-20 and OS-6 is shown in Figure 30. The yield index is defined as the grain: straw ratio. The data indicate no significant differences in the yield index of IR-20 and OS-6. Soil moisture stress of 250-cm suction, however, significantly suppressed the yield index, more of OS-6 than of IR-20.

Conclusions

1. Along with appropriate field studies, greenhouse evaluation can be useful in screening rice varieties for drought resistance. The yield components that are most drastically affected by drought stress include floral sterility, unit grain weight, and panicle number.

2. The stage when rice is most vulnerable to drought stress is from maximum tillering to heading.

   Some conclusions from the greenhouse studies at IITA comparing the effects of drought stress on IR-20 and OS-6 are summarized below:

   a. Increase in cumulative moisture stress was accompanied by a decrease in total amount of water used by each rice variety. This can be explained thus: that increase in cumulative moisture stress has a direct effect in reducing the growth and development rate of the rice plant. This effect is exhibited by the production of small-sized plants that need a limited quantity of water to carry out their metabolic processes. Thus, growth is consistently reduced and water use correspondingly limited.

b. Some moisture stress (such as existed in a saturated but unsubmerged soil) increased the grain yield of OS-6. This observation must be related to the intrinsic characteristics of OS-6 rice plant to perform better under upland conditions than in flooded paddies, provided however, there is adequate supply of water for good growth and development.

c. The main effect of high moisture stress on both rice varieties seems to have been in prolonging duration of vegetative growth coupled with decrease in yield.

d. The critical moisture potential for OS-6 is lower (more negative) than that of IR-20.

e. Consequently OS-6 outyielded IR-20 at all levels of soil moisture stress.

f. The yield differences in OS-6 over that of IR-20 were attributed to the former's ability to produce bold grains, a higher number of grains/panicle and longer panicles.

g. Although the number of tiller production in IR-20 was greater than in OS-6, OS-6 was definitely superior to that of IR-20.

h. Some characteristics of OS-6 that are unfavorable to upland conditions, include leafy canopy and lodging, caused by soft, slender and long straw. Genetic manipulation can, therefore, be done to transfer superior shoot characteristics into OS-6 to further improve its performance under upland conditions.

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9. PLANT-WATER STRESS IN RELATION TO SOIL MOISTURE POTENTIAL

Little work has been done on the effects of moisture stress on leaf moisture potential and transpiration rates of rice. Larcher (1963) observed that among crop plants investigated, "only the ephemerous annuals were exceptional by their high productivity per unit transpiration"; i.e. they yield considerable dry matter with relatively low transpiration. Maximor (1923) working on potted plants grown under soil moisture conditions of 40-60 percent of field capacity reported that all the plants grown in the drier soils yielded less dry matter and that 7 out of 12 plants in the dry soils reduced their transpiration more than their dry matter production, so that these plants transpired more profitably than their control, which received an optimal amount of water. Tulaikov (1922) and Tumanov (1927) have reported similar results. Tumanov measured water consumption and dry matter production of some cultivated plants throughout development from seedling to harvest and calculated the efficiency of transpiration for each stage of development. He observed that the efficiency of transpiration will increase with increasing soil dryness on the average over an entire growing season, provided that wilting does not occur too frequently or for too long during critical growth stages.

The work reported by many researchers (Loustalot, 1945; Polster and Neuwirth, 1960; Neuwirth and Polster, 1960) concerning water stress and efficiency of transpiration indicates that the efficiency of transpiration increases with increasing soil dryness, on the average over an entire growing season. This was also observed for rice as shown by the data presented in Chapter 8.

Theoretically, decreasing transpiration is only a matter of increasing the resistance existing in the series of conductors; the soil itself, cells of the root, xylem cells, the epidermis and the diffusion as it occurs across the stomatal inter-cellular space into the atmosphere. However, most of the resistance to transpiration lies in the epidermis of the leaf and the air above it (Spencer, 1957, and Waggoner 1965). In terms of transpiration it has been reported that stomatal resistance (r_s) becomes limiting but with wide stomatal openings the external environmental factors (r_a) are more effective on transpiration rate (Stalfelt, 1956). However, from works of Larcher (1963) Gaastra, (1959; 1962) and Visser, (1963), the rate of efficiency of transpiration is determined by the diffusive resistances existing in the leaf epidermis which depend on leaf temperature and the vapor pressure deficit in the air.

Stomatal behavior can be used as an index in investigating drought resistance in rices. Experiments conducted at International Rice Research Institute (1973, 1975) indicated that there was a higher stomatal resistance in upland than in lowland rice varieties when grown under similar conditions of soil moisture stress. However, stomatal behavior is not a critical test, because its response depends on many factors.

Martin and Juniper (1970)have reviewed the physiological effects of cuticular resistance to water loss during drought stress. However, the water loss through cuticles is rather small compared with total evapo-transpiration. Larcher (1976) reported that cuticular water loss ranged from 0.05 percent to 32 percent in different species. Yoshida and Reyes (1976) reported cuticular resistance values of 116 and 112 sec/cm for sorghum and maize, and that of the resistance of upland rice varieties was observed to be more than that of lowland.

In most of the studies reported, the exact effect of the soil drying on various growth phases of crop plants and on the moisture relations of the plant itself is not investigated. Mukherjee and Narala (1973) measured the diffusion pressure deficit (DPD) in rice leaves over a 42-day period. The DPD, monitored by the dye immersion technique was negatively correlated with soil moisture content. In the first 10 days, moisture depletion of the order of 5.25 percent, had little effect on the leaf DPD. An increase of 85 percent in DPD was observed for the last 22 days when the soil moisture content under rice decreased from 14 to 4.2 percent. Similar studies have been reported by Singh and Pande (1973), although they did not observe any significant differences in tissue hydration among rice plants grown under submergence, cyclic submergence, or saturated soil conditions. Nevertheless, the tissue hydration decreased significantly with increase in soil moisture stress, during any phase of crop growth.

Tomar and Ghildyal (1973 a, b) reported diurnal variations in water deficit, resistance to water transport, and the internal plant-water relations of IR-8 rice. Wilting in IR-8 occurred at a turgor pressure rather than due to the complete absence of the turgor pressure. Wilting was also found to be associated with marked change in the elastic properties of the leaf tissue. The wilting also occurred simply due to change in the resistance to water movement in plant tissues, and was not even directly related to the 15 bar soil moisture suction. Tomar and Ghildyal (1973b) also compared transpiration rate and leaf water potential of rice grown under submerged conditions with that grown at soil moisture suction of -0.33 bar for 56 days followed by no irrigation until when wilting occurred. The transpiration rate decreased with increase in leaf water potential (more negative), but it was independent of the depletion of soil moisture content above 0.21 (-0.8 bar) and 0.18 (-2.0 bar) for plants grown in submerged and unsaturated soil conditions, respectively.

Greenhouse studies were conducted at IITA to investigate the effects of soil moisture stress on leaf moisture potential and the diffusive resistance. Leaf moisture potential was monitored by Pressure Bomb equipment. The diffusive resistance was measured by Diffusive Resistance Meter Model L1-60, technique developed by Kanemasu et al (1969). Leaf moisture potential measurements were made at (i) mid tillering, (ii) panicle initiation, (iii) 50 percent flowering, and (iv) at grain filling stage at 0730, 1100, 1400, and 1600 during 3 consecutive days. Leaf diffusion rates were monitored simultaneously on identical or the same leaves before they were detached for the Pressure Bomb measurements.

In determining the leaf resistance (r_s) the following procedure was followed: Horizontal Sensor Model L1-15S was used to measure leaf moisture diffusion rates in IR-20 and OS-6. The leaf was inserted between the sensor cups before meter readings were taken. With the rubber bulb attached to the dry tube, dry air was pumped into the sensor cup until the meter read 10 on HUM-2 range. This level of drying was maintained for all meter readings throughout the experiment so as to ensure the essential accuracy needed in the readings obtained by this meter.

The meter was calibrated to transit times between 40 and 80 (HUM-2 range) and the time lapse between 40 and 80 for each leaf was measured with a stop watch. This time lapse was recorded as 't' for each leaf. The air temperature for the leaf was also read and recorded in Micro-Amperes from the meter. Micro ampere readings were converted to degrees centigrades (^{o}C) by the use of a calibration curve. The temperature was also obtained from the slope curve. Leaf resistance, r_s, was calculated from the following equation:

$$r_s = r_o + t/s$$

where r_s = Leaf resistance

s = Temperature slope ($^{t}/r$)

r_o = -2.4 sec. cm^{-1}, intercept of temperature calibration lines on the abscissa.

t = Time lapse between 40 and 80 meter transit time on HUM-2 range.

Three sample readings were taken per treatment and the average resistance recorded.

This diffusion poro-meter and the accompanying moisture sensors are capable of determining resistance to water loss by intact leaves with a high degree of accuracy. A bead thermistor forms a component part of the sensors and this presses gently against the leaf to permit leaf temperature measurements simultaneously.

In estimating the Leaf Moisture Potential the pressure chamber technique was employed. Leaves of IR-20 and OS-6 rice varieties were sampled for this determination. Care was taken to sample areas of leaf blade that had identical exposure to or shading from incoming radiation. These samples were taken from adjacent areas on both sides of the mid-vein. The leaf half was slipped between the smooth surface of a split rubber stopper previously coated with silicon grease and inserted into the inner cover which was then fixed on top of the pressure bomb chamber.

With the bleeder and flow regulating valves closed and the gauge shut-off valve opened, pressure was applied from a cylinder of compressed nitrogen through the pressure regulator. As the regulating valve was opened, pressure was gradually increased at a uniform rate of about 10 pounds per second. The cut end of the leaf protruding about 6 mm above the surface was observed with a magnifying glass. When water first appeared along the cut surface of the leaf the pressure reading was quickly recorded and the regulating valve closed. Then the bleeder valve was opened to vent out the system of the compressed air. When the pressure gauge read zero, the outer cap was unscrewed and the leaf sample was removed from the pressure chamber.

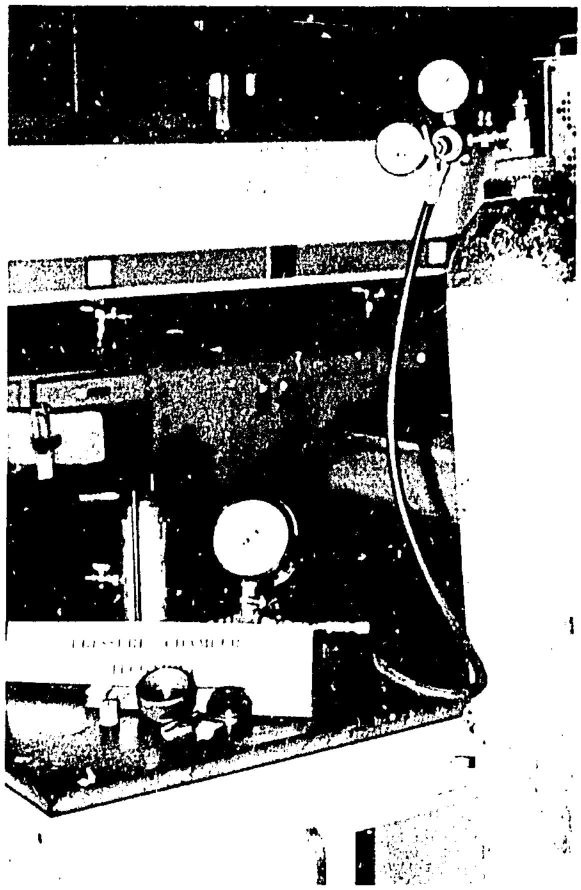
The analysis of variance table of F ratio and the numerical data of the leaf diffusive resistance and leaf moisture potential are shown in Tables 1, 2 and 3, respectively. There are significant effects of variety and soil moisture regimes on both the diffusive resistance and the leaf water potential. Detailed analysis of the results is presented below:

Diffusive resistance. Leaf resistance to water loss (r_s), a measure of leaf moisture diffusion rate at different stages of growth, is shown in figures 1-5. At mid-tillering stage (Fig. 1), there was a significant increase in leaf resistance with increase in moisture stress under this investigation. The varietal effects on the leaf diffusive resistance were not significant. The leaf diffusive resistance increased with increasing moisture stress from zero suction to 250-cm suction.

At panicle initiation stage (Fig. 2), there were no significant differences in the leaf diffusive resistance of IR-20 and OS-6 for the soil moisture regime of submergence, saturated soil, and suction ranges of up to 100 cm of suction. But the highest soil moisture stress of 250 cm, the diffusive resistance of OS-6 was significantly higher than that of IR-20.

Within a given variety, moisture regimes had a highly significant effect on leaf resistance at mid-tillering and at panicle initiation stage.

(2)



(1)

Plate 1. Pressure chamber for monitoring leaf water potential.

Plate 2. Monitoring leaf water potential in the green house.

Table 1. Analysis of variance table of F ratio.

Source of variation	Leaf resistance at panicle initiation	Leaf resistance at flowering	Leaf resistance at grain filling	Leaf moisture potential at flowering	Leaf moisture potential at grain filling
Variation (V)	0.21	0.35	10.9**	10.1**	106**
Moisture regime (M)	6.0**	5.2**	0.5	2.7*	9.6**
VXM	1.9	0.8	0.6	0.7	0.7

Table 2. Diffusive resistance in IR-20 and OS-6 at different soil moisture regimes (Sec. cm^{-1}).

Soil moisture regime	Panicle initial		50% flowering		Grain filling	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	3.79	2.79	3.26	3.34	3.43	4.57
Saturated	4.19	3.84	3.23	3.94	3.53	4.11
Zero suction	3.95	3.70	3.15	3.23	3.01	4.60
25-cm suction	4.02	3.19	3.05	3.37	3.26	4.19
50-cm suction	3.81	3.89	3.65	3.55	3.27	4.27
75-cm suction	4.15	3.89	3.75	3.55	3.79	4.15
100-cm suction	4.43	4.21	3.59	4.05	3.93	4.64
250-cm suction	4.98	6.95	5.07	4.49	4.34	4.29
LSD (.05)	0.47		0.32		0.48	
LSD (.05)	0.62		0.43		0.64	
CV (%)	22.8		17.5		24.0	

Table 3. Influence of soil moisture regimes on leaf moisture potential (lb/sq. foot).

Soil moisture regime	Flowering stage		Grain filling stage	
	IR-20	OS-6	IR-20	OS-6
Submerged	235	194	221	161
Saturated	224	210	210	164
Zero suction	210	179	208	174
25-cm suction	201	204	229	179
50-cm suction	230	205	225	206
75-cm suction	218	208	250	194
100-cm suction	234	232	240	194
250-cm suction	259	224	271	218
LSD (.05)	12.5		9.2	
LSD (.05)	17.0		12.2	
CV (%)	11.7		8.7	

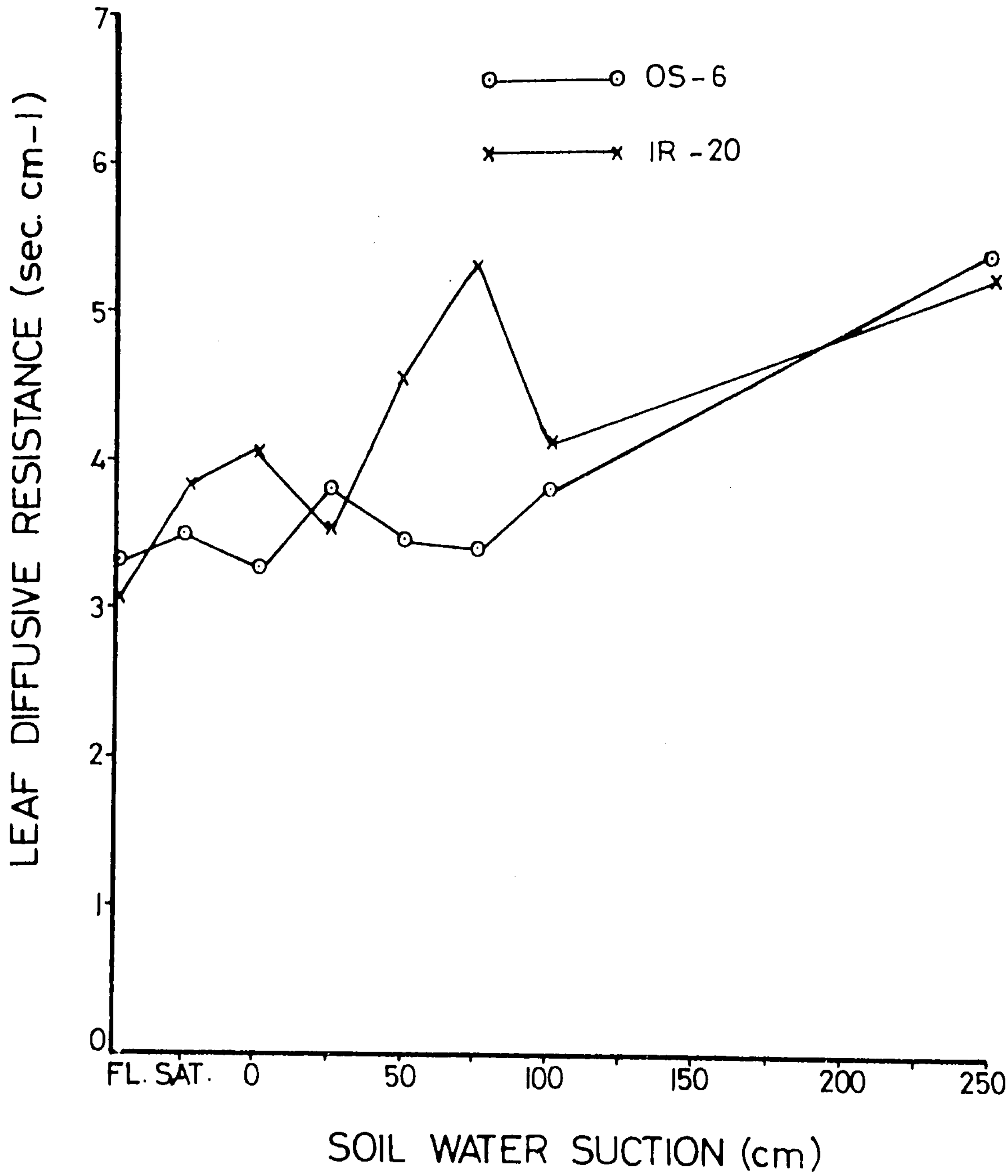


Fig.1. Leaf diffusive resistance as affected by the soil moisture regime.

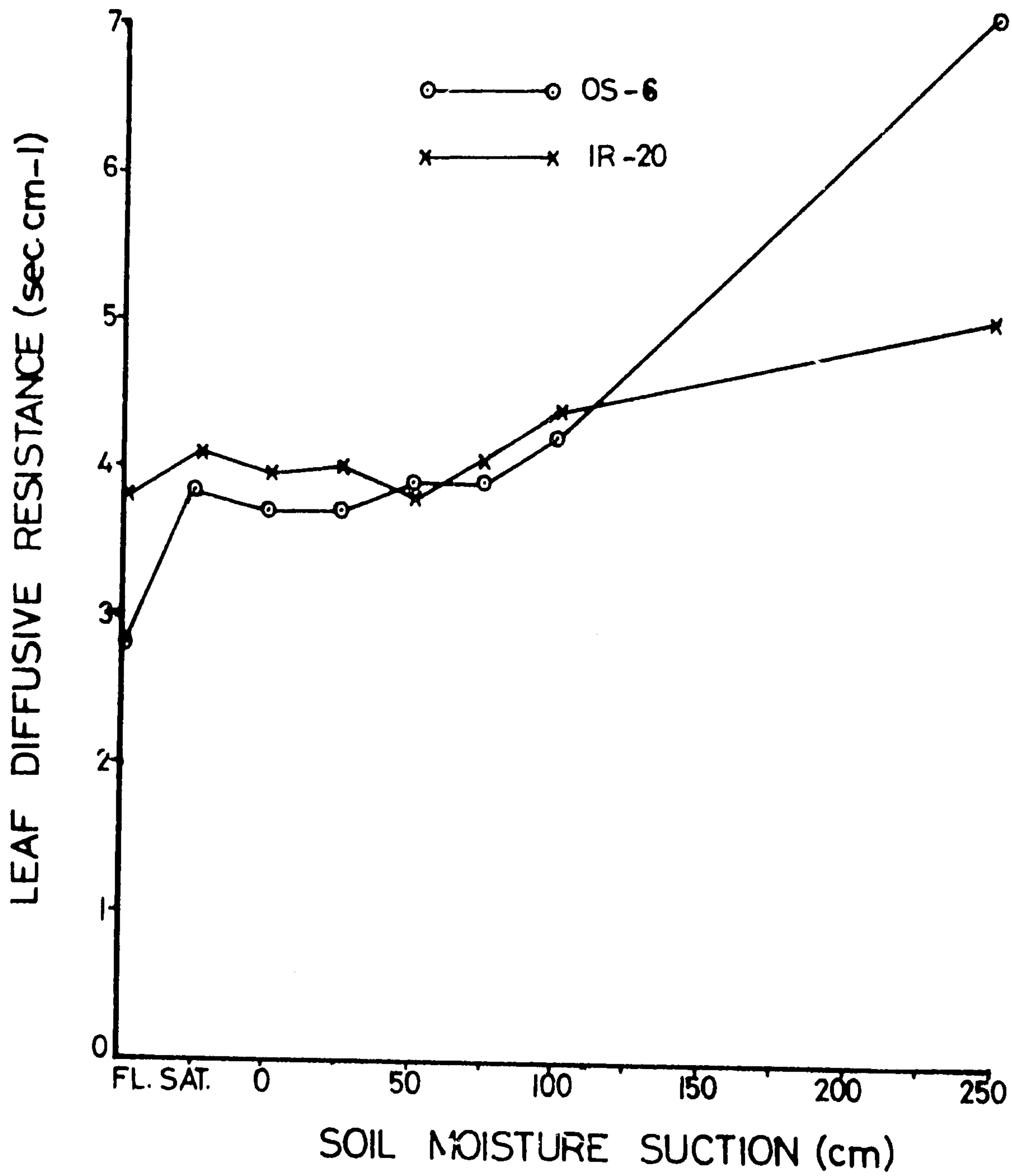


Fig.2. Effect of soil moisture regime on leaf diffusive resistance measured at the panicle initiation stage.

The relative increase in the diffusive resistance of OS-6 at high soil moisture suction was greater at panicle initiation stage than at mid-tillering stage of rice growth.

At the flowering stage (Fig. 3) OS-6 also showed higher diffusive resistance than IR-20 for most of the moisture regimes investigated. The differences in the diffusive resistance among two varieties were not significant. Moreover, the relative increase in the diffusive resistance (r_s with increase in soil moisture stress was only slight. It is interesting to observe that cloudy atmosphere with low, incoming radiation, high humidity and low ambient temperature was responsible for this slight difference in the diffusive resistance.

The data in Figure 4, concerning the leaf diffusive resistance of IR-20 and OS-6 at grain filling stage indicate significant differences in both varieties. OS-6 had significantly higher leaf diffusive resistance than IR-20 at all moisture regimes. This implies that the resistance of OS-6 to dehydration is greater than that of IR-20.

Figure 5 shows the variation in leaf resistance at different growth stages. The highest resistance to water loss was observed at panicle initiation followed by that at the grain-filling stage. The lowest r_s occurred at the 50 percent flowering stage of growth. From mid-tillering to panicle initiation stage, OS-6 had higher r_s values than IR-20. Obviously, these are the critical growth stages for grain development. These observations indicate differences in mode of leaf resistance to water loss through transpiration at various growth phases of IR-20 and OS-6. Further physiologically oriented research is required to investigate anatomical differences in leaf structure of IR-20 and OS-6.

Leaf moisture potential. Figures 6, 7 and 8 show the leaf moisture potential of IR-20 and OS-6 at both flowering and grain-filling stages. There was a significant decrease in leaf moisture potential with increase in moisture stres , in the two varieties. However, there were significant differences in the leaf moisture potential of IR-20 and OS-6, at a given soil moisture stress. IR-20 had a lower leaf-water potential (L_ψ) at the flowering stage (Fig. 6) at all the soil moisture regimes, except for the submerged treatment when there were no differences in soil moisture potential. The leaf moisture potential of OS-6 was higher than IR-20 by 12, 5, 15, 10, 5, 8, and 2 percent respectively for soil moisture regimes in the increasing order of soil moisture stress. The varietal differences were more pronounced in the medium range of moisture stress.

At the grain filling stage (Fig. 7), there were no definite trends in the leaf moisture potential of both varieties. Though in both varieties the leaf moisture potential decreased with increase in soil moisture stress. This contrast in the leaf moisture potential of two varieties at flowering stage and grain filling stage may be attributed to the differences in physiological growth stages of two varieties, not only

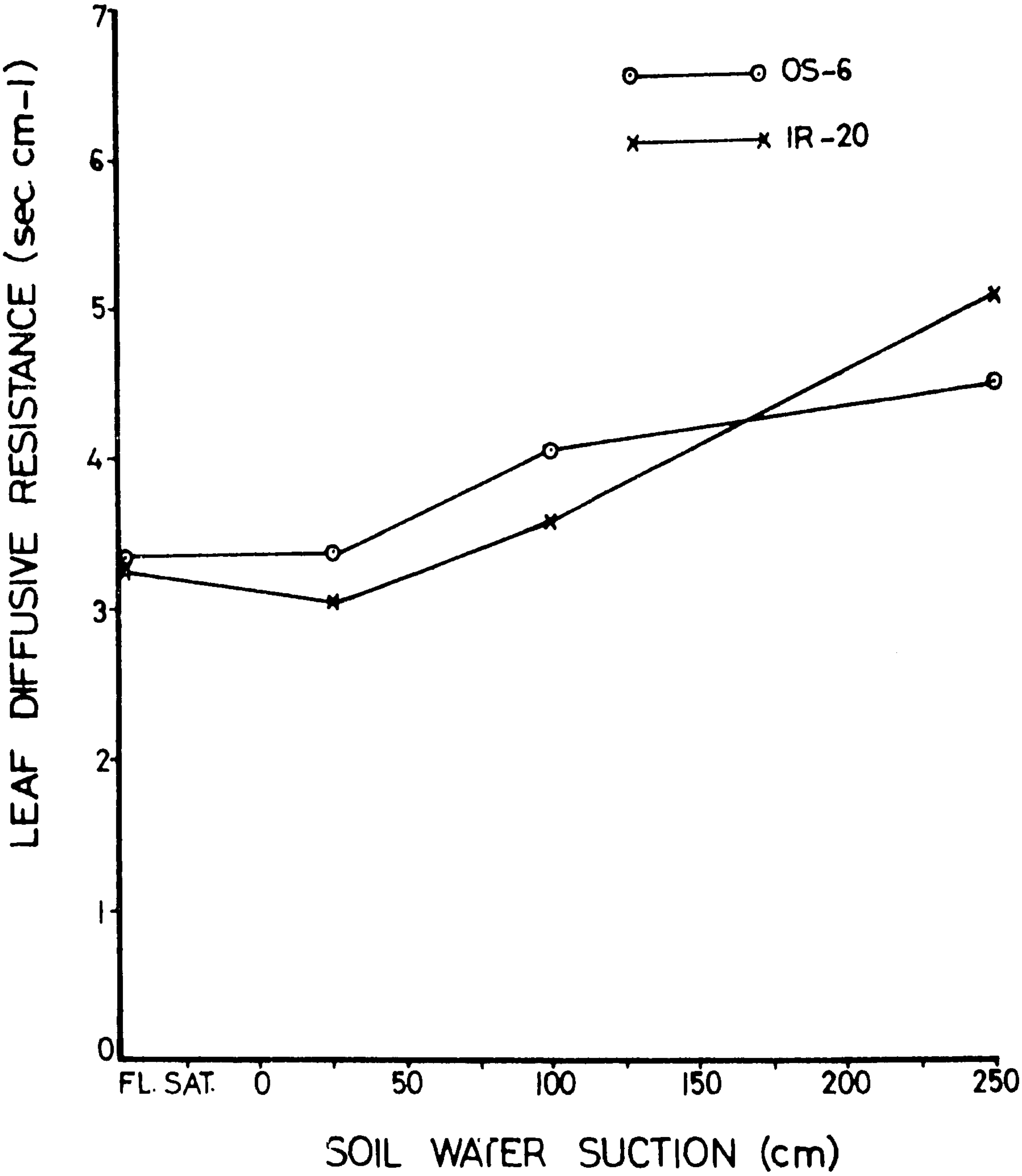


Fig.3. Leaf diffusive resistance measured at the 50% flowering stage.

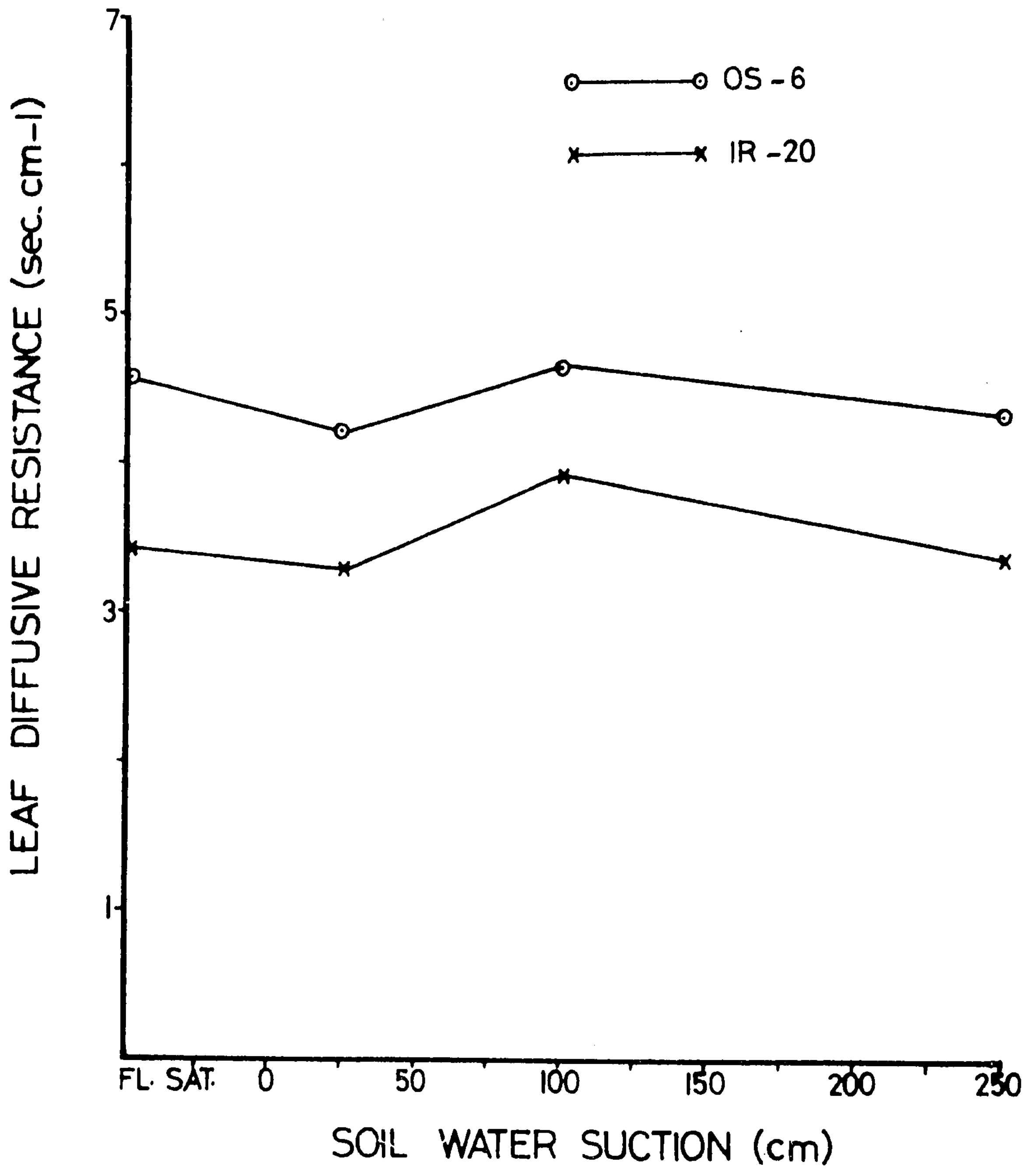


Fig.4. Effect of soil moisture regime on leaf diffusive resistance measured at the grain filling stage.

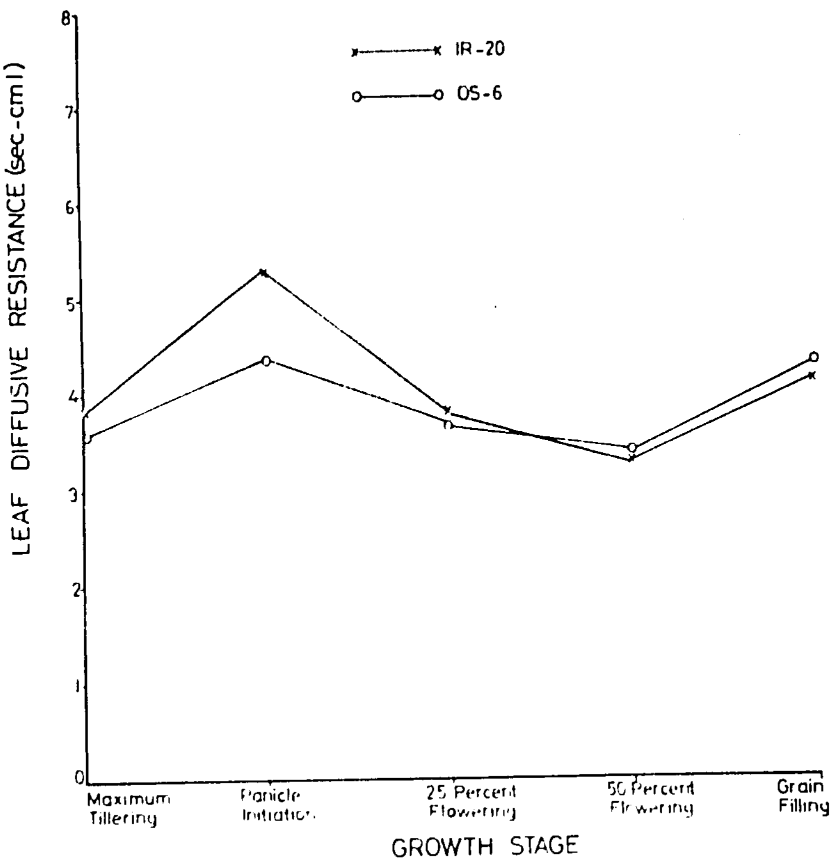


Fig.5. Changes in leaf diffusive resistance at different growth stages.

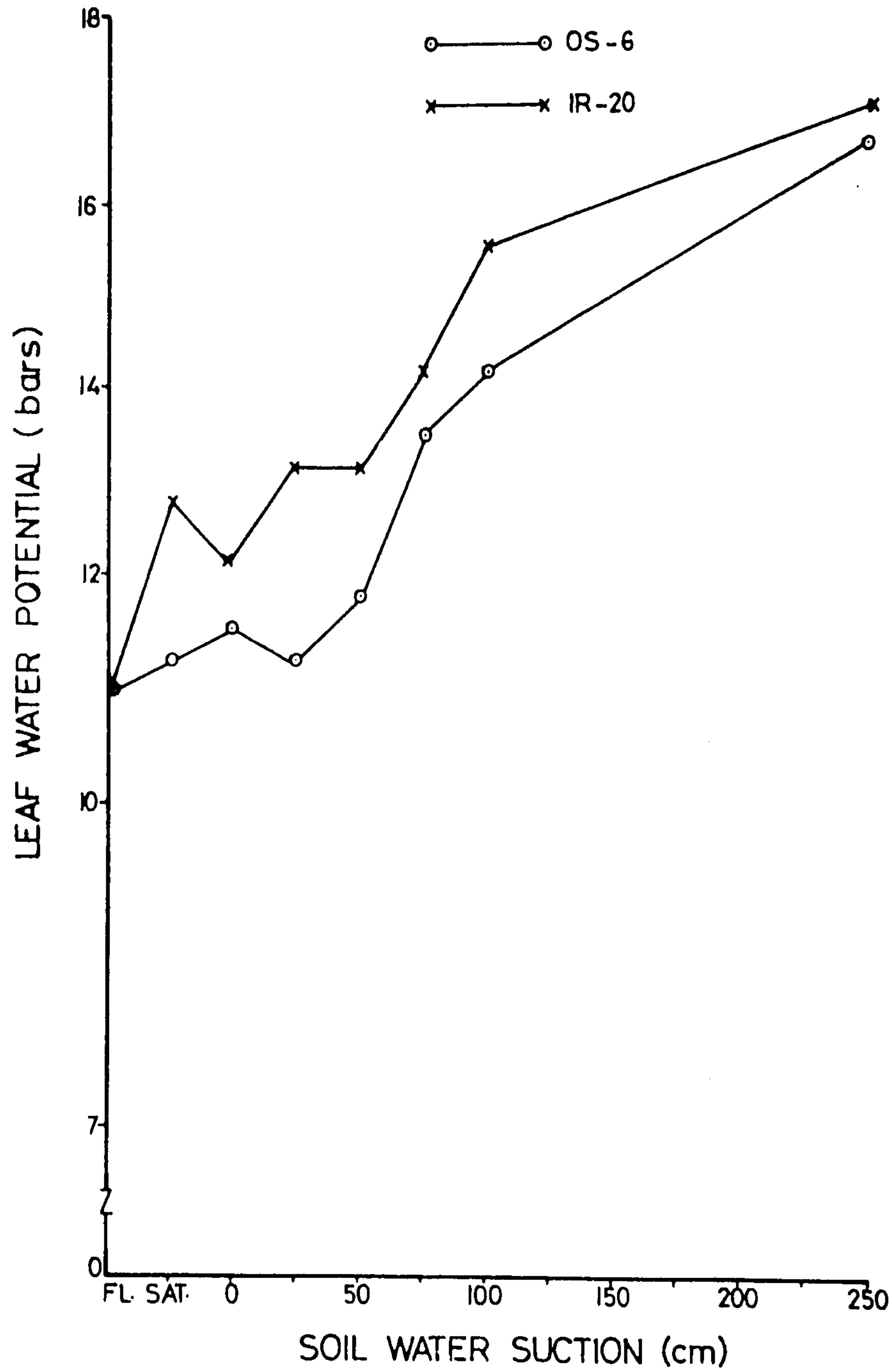


Fig.6. Effect of different soil moisture regimes on leaf water potential.

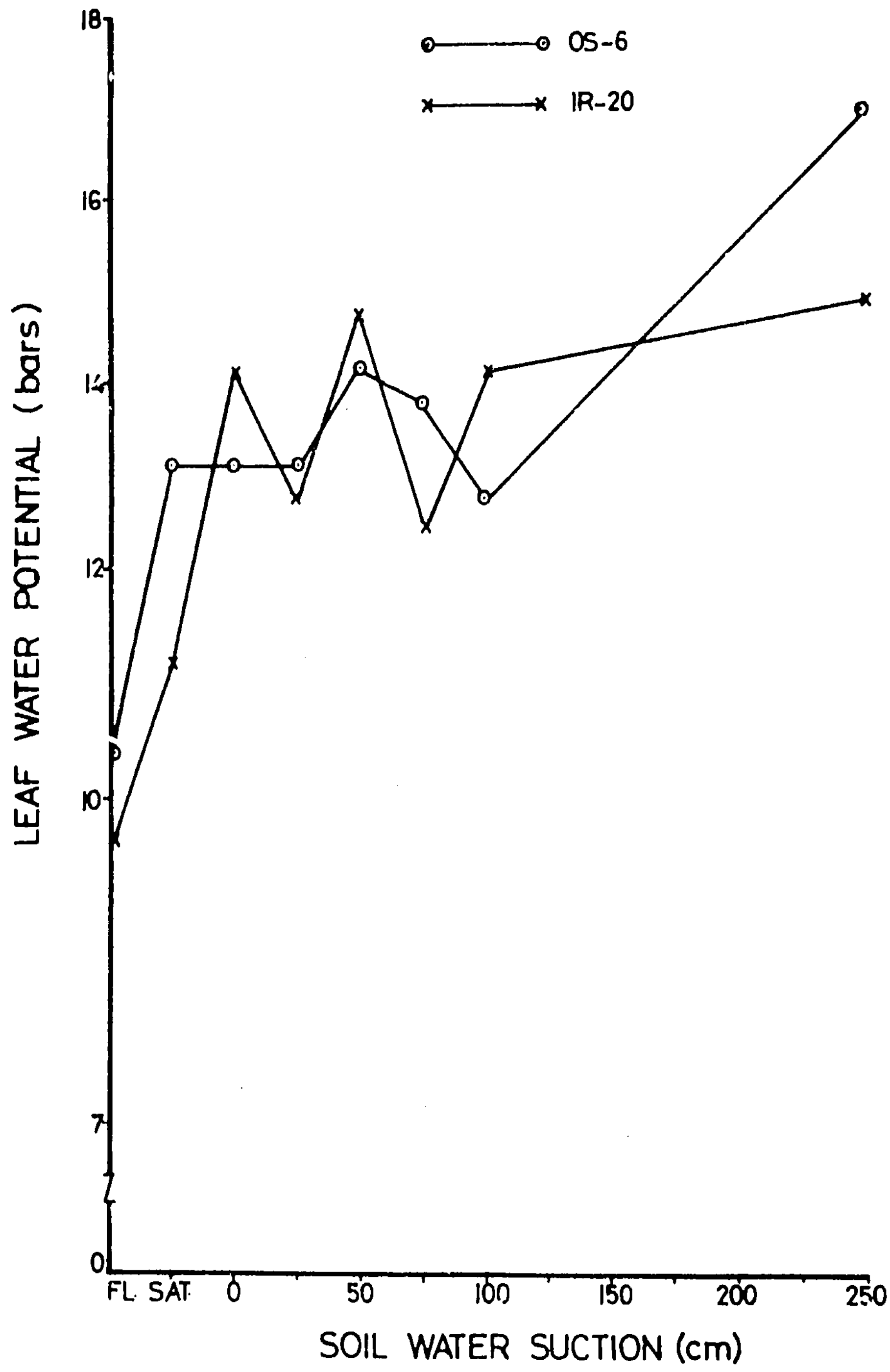


Fig.7. Effect of soil moisture regime on leaf water potential at the grain filling stage.

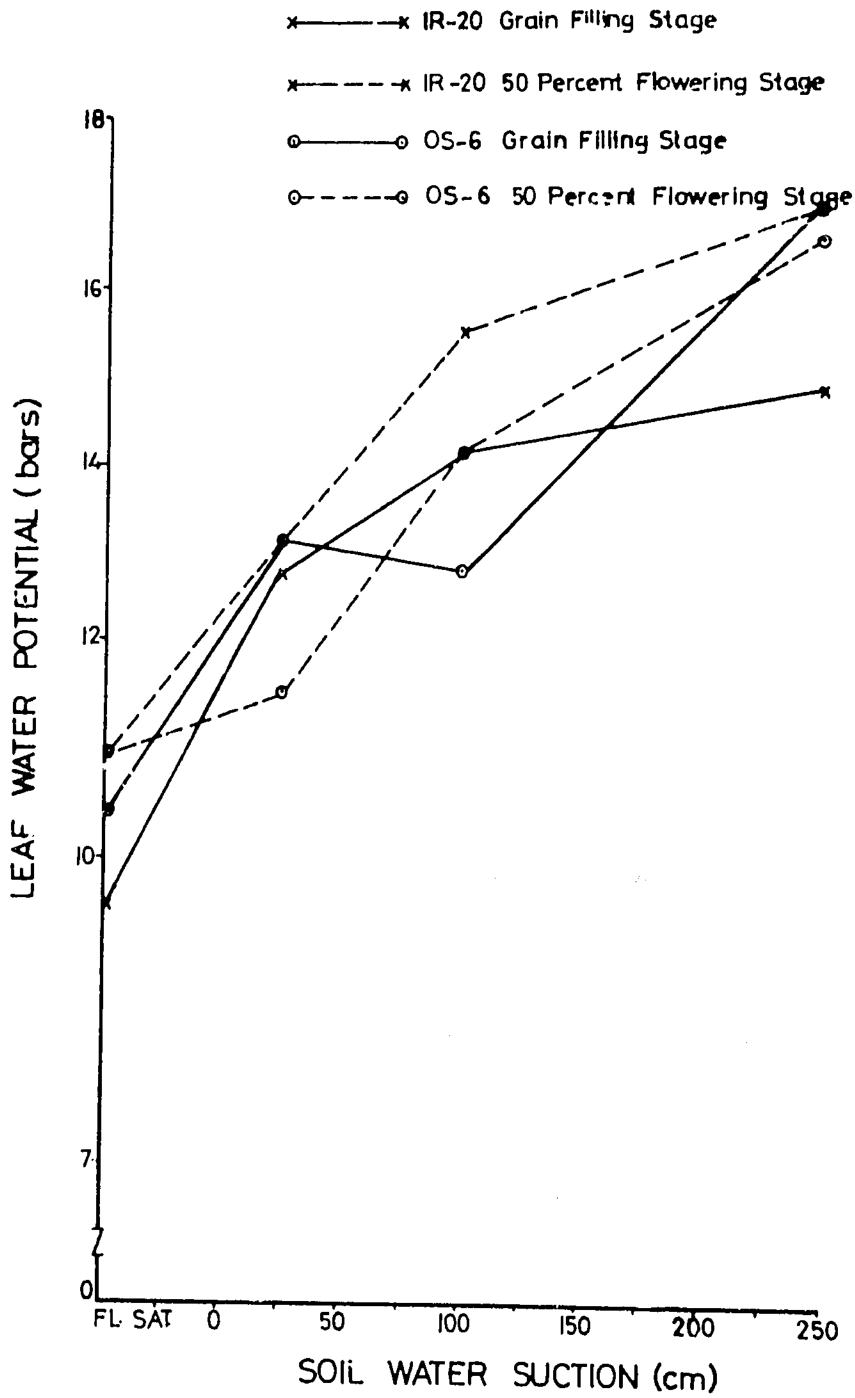


Fig.8. Effect of soil moisture regimes on leaf water potential at 50% flowering and grain filling stages.

to differences in maturity time but also due to differential lag imposed by the soil moisture stress on physiological growth stage of the two varieties. Comparison of the leaf moisture potential of the two varieties for these two stages of growth is shown in Fig. 8. There was a significant decrease in the leaf moisture potential of IR-20 at the grain filling stage compared with the flowering stage. OS-6 did not show any significant change in the leaf moisture potential at a given stress during these two growth stages.

The leaves of different ages sampled for leaf moisture potential indicated a wide variation in potential values for the old compared to young leaves (Fig. 9). Leaves 5 and 6, the oldest, had lower leaf moisture potential than the most active leaves. The variation in leaf moisture potential of leaves, 1, 2, 3, and 4 was somehow noteworthy, and do not differ significantly among one another. Because these are regarded as the most active leaves, leaf 2 was chosen for the standard measurements, such as those reported in Figures 7-9.

Measurements of the leaf moisture potential made at different times of the day (Fig. 10) showed a wide variation in the potential values for the two stages of growth. At the flowering stage, the leaf moisture potential of submerged treatments of both IR-20 and OS-6 decreased with increase in time from 0800 hour to 1000 hour. But there was a significant decrease in the leaf moisture potential at 1300 hour, the period of highest evaporative demand. The leaf moisture potential of the highly stressed plants (250 cm suction) did not show any significant diurnal changes.

The diurnal fluctuations in the leaf moisture potential at the grain filling stage were significantly different from those at flowering stage of rice growth. The highest (lesser negative) leaf moisture potential was observed during the early hours (0800) of low evaporative demand. The leaf moisture potential decreased significantly with increase in the evaporative demands later in the day (Fig. 10b). Once again IR-20 had lower leaf moisture potential than OS-6, particularly at high suction (250 cm) and when the evaporative demand was high (1300 hour). These results are quite significant when characterizing the growth parameters of IR-20 and OS-6 in terms of their response to soil moisture stress.

Transpiration rate. The leaf moisture potential and the diffusive resistance are the components of transpiration rate. The efficiency of transpiration at the different growth stages as affected by soil moisture regimes is shown in Figures 11-15.

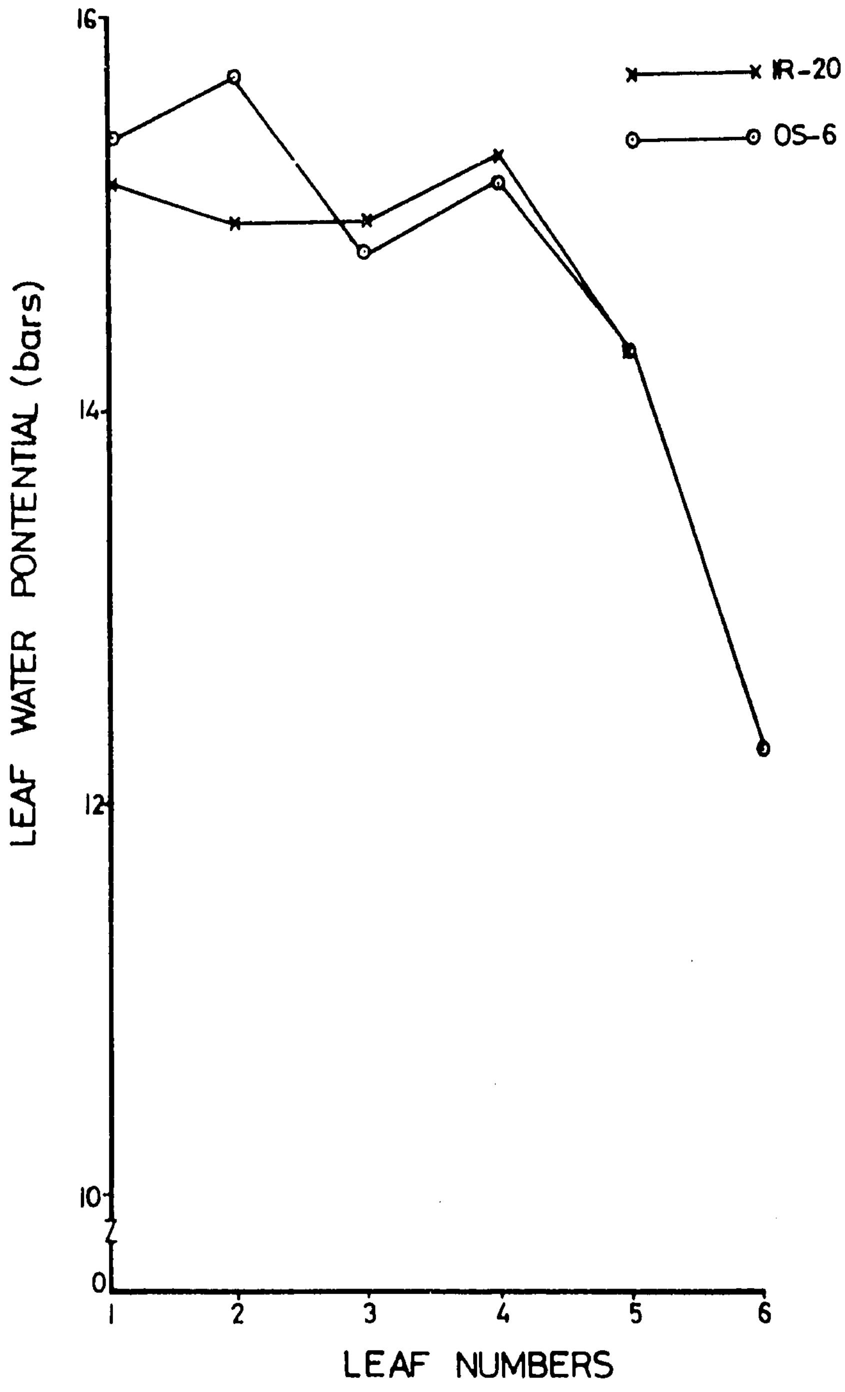


Fig.9. Effect of leaf age on the leaf water potential.

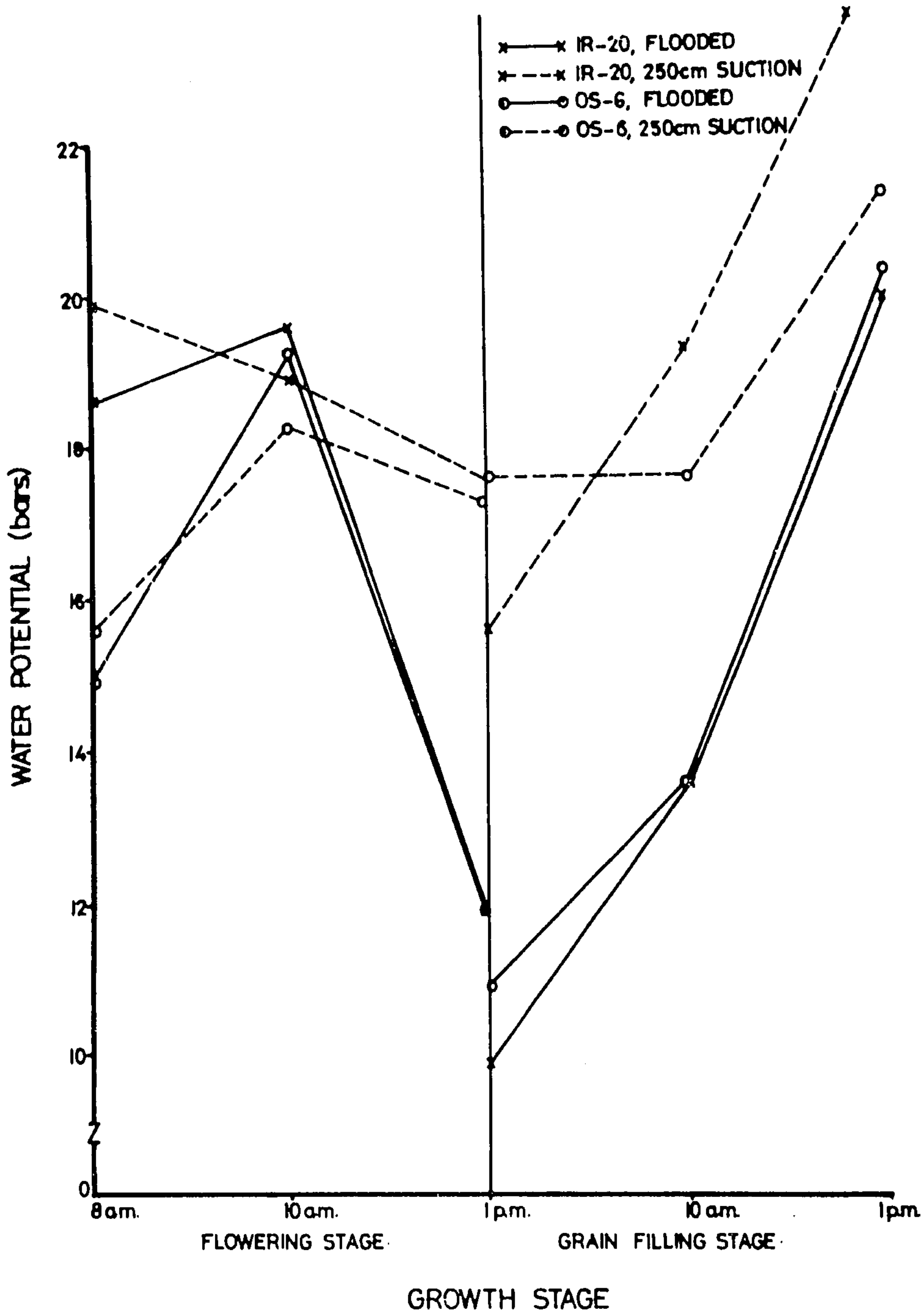


Fig.10 Diurnal fluctuations in leaf water potential.

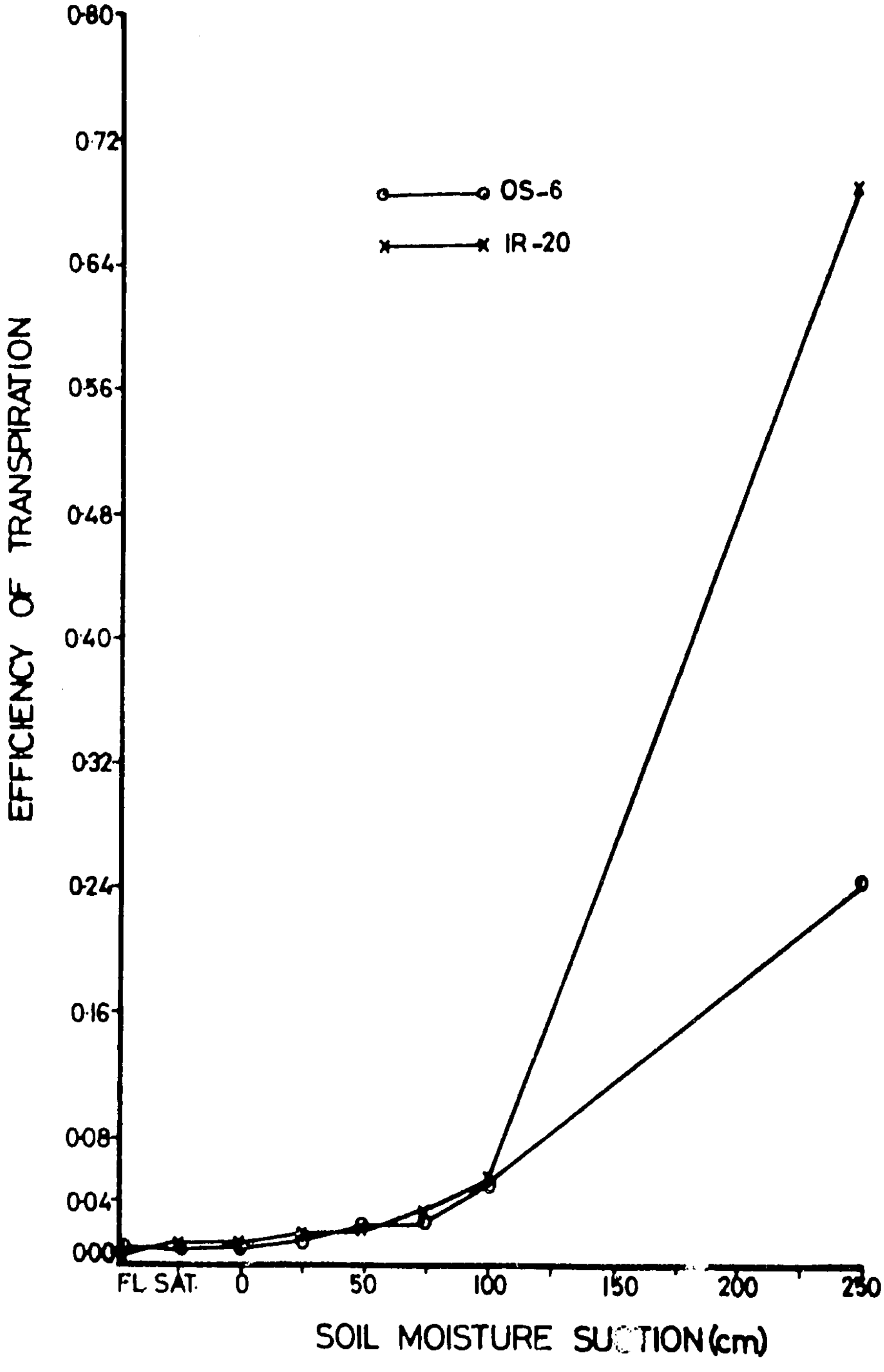


Fig.11. Effect of soil moisture regime on the transpiration efficiency at seedling stage.

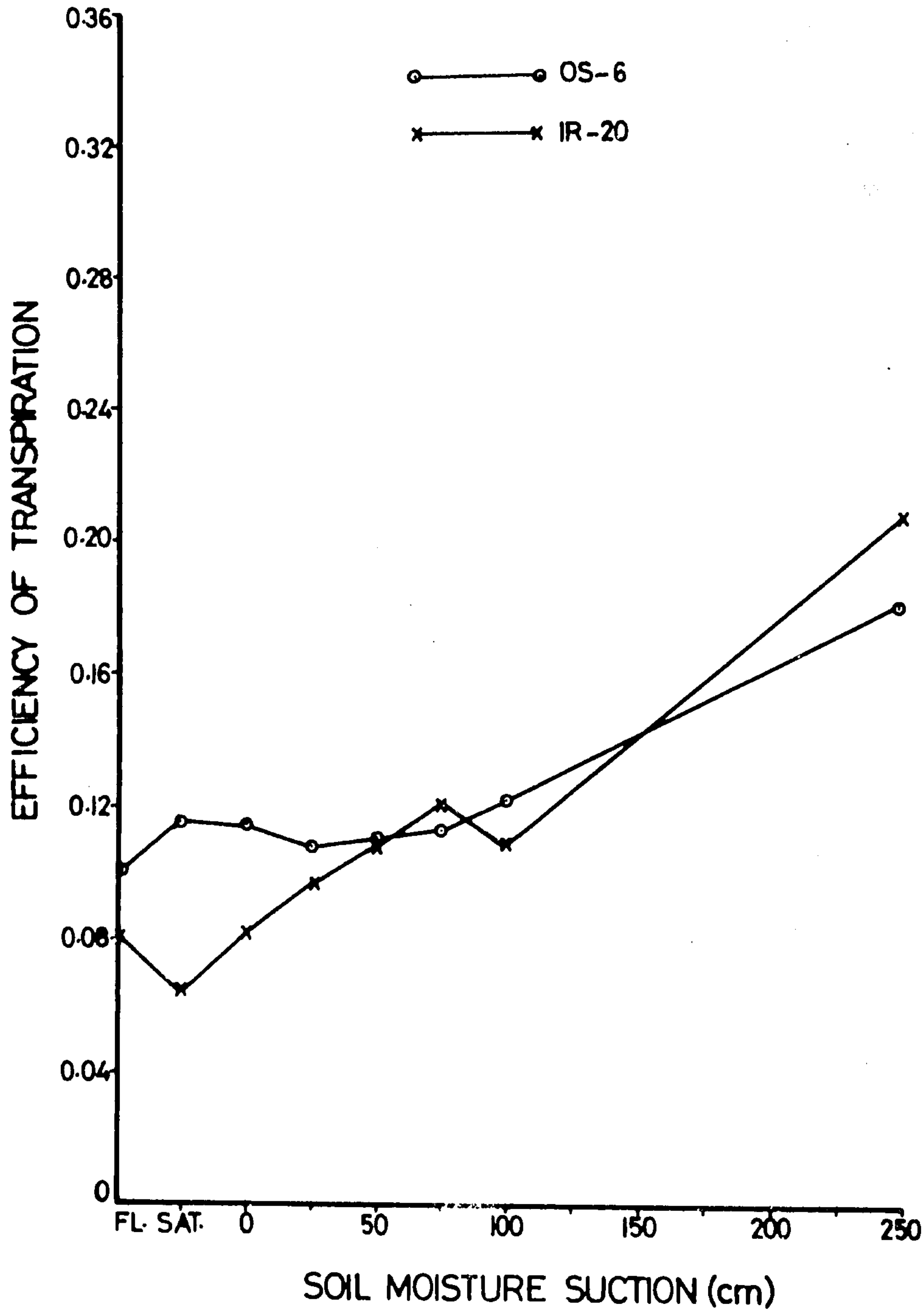


Fig.12. Effect of soil moisture regime on the transpiration efficiency at tillering stage.

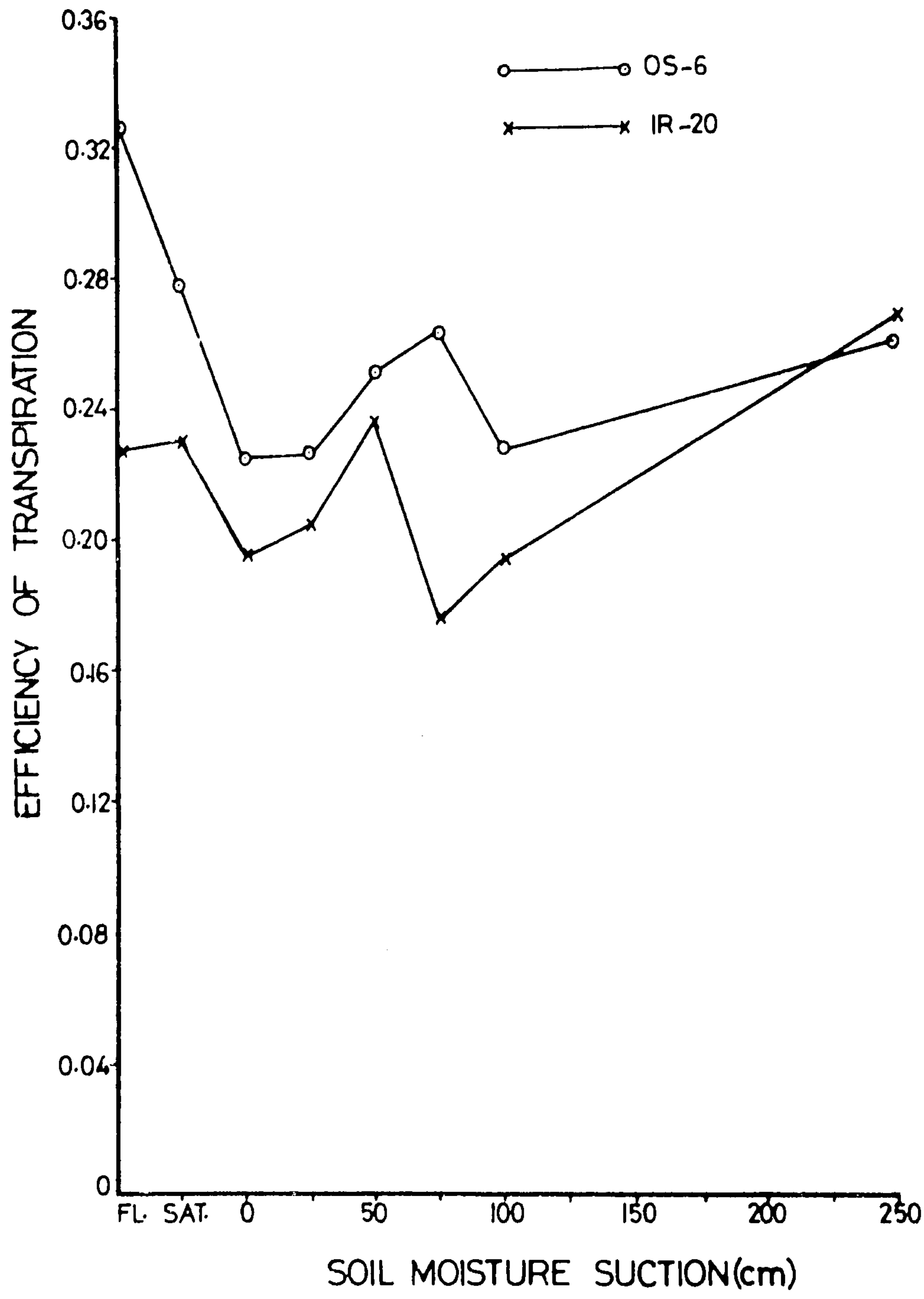


Fig.13. Effect of soil moisture regime on the transpiration efficiency at the grain filling stage.

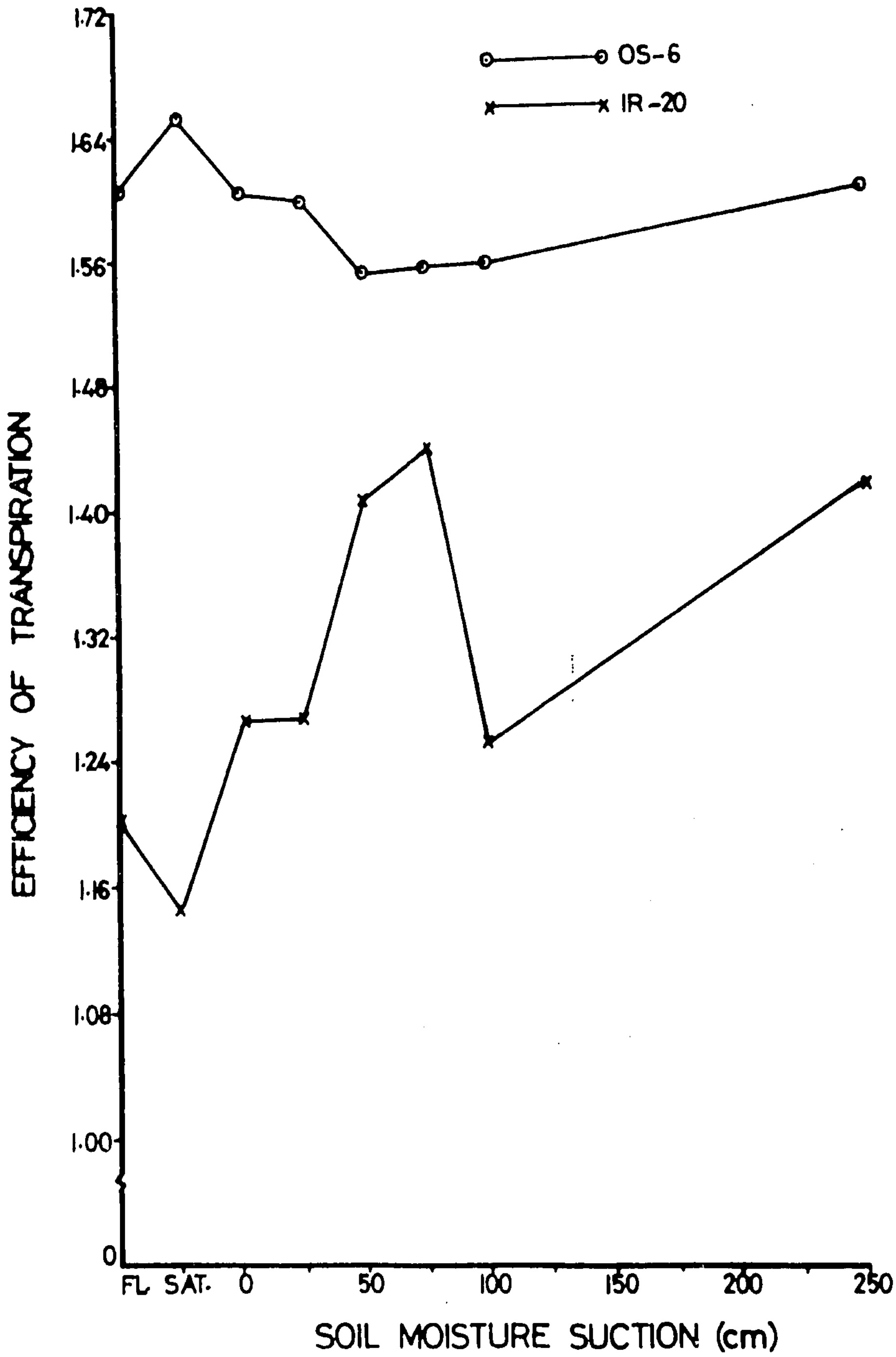


Fig.14 Effect of soil moisture regime on the transpiration efficiency at maturity.

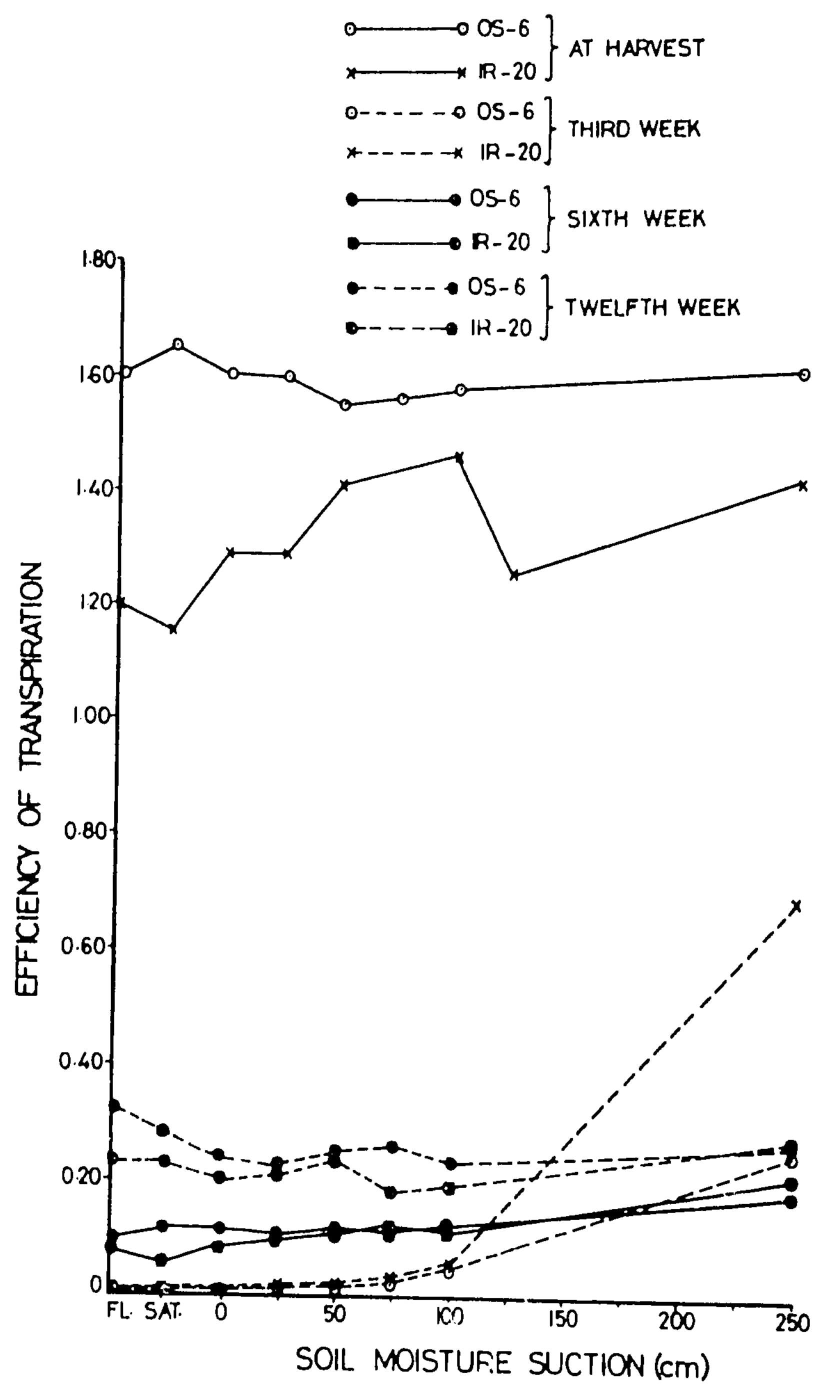


Fig.15. The transpiration efficiency of IR-20 and OS-6 at different growth stages.

At the seedling stage (Fig. 11), the efficiency of transpiration did not differ between the two varieties at low moisture stress. Up to a soil moisture suction of 100 cm, there were no differences in the transpiration efficiency, and the mean value was about 0.03. There was a slight increase in the transpiration efficiency, with increase in moisture stress. The transpiration efficiency at the tillering stage (Fig. 12) was significantly greater than at the seedling stage. Though the varietal differences were not significant at the high soil moisture stress, the transpiration efficiency of OS-6 was greater than that of IR-20 at low level of soil moisture stress e.g. below 100 cm of water suction.

The transpiration efficiency generally increased with an increase in growth stage (Figs. 13 and 14). At the grain filling stage, the transpiration efficiency of OS-6 was greater than IR-20, but did not significantly decrease with increase in moisture stress. The transpiration efficiency of IR-20, however, declined from submergence to 25 cm suction. At 250-cm suction, the varietal differences were non-existent.

There were significant varietal differences in the transpiration efficiency at maturity (Fig. 14). The OS-6 had higher efficiency than IR-20 at all moisture regimes. The transpiration efficiency of OS-6 did not differ significantly with increase in moisture stress, but that of IR-20 increasedup to a soil moisture stress of 75 cm. Significant influence of growth stage on the transpiration efficiency of IR-20 and OS-6 is shown in Fig. 15 and Table 4.

Yield in relation to leaf moisture status. In Table 5 are shown coefficients of linear correlation of leaf moisture potential and diffusive resistance with grain and straw yield and other yield parameters. Leaf moisture potential at 50 percent flowering and at grain filling stage had a significant negative correlation with grain yield, straw yield, number of grain/panicle, panicle/weight, unit grain weight, dry matter production at various growth stages, and with plant height at flowering and at harvest. Number of days to heading were positively correlated with leaf moisture potential. The correlation coefficient of leaf resistance with yield and parameters were generally lower than that with leaf moisture potential. Leaf resistance measured at grain filling stage had no correlation with grain and straw yield. Leaf resistance at panicle initiation and at 50 percent flowering showed a significantly negative correlation with grain yield, straw yield, and number of panicles/pot. There was a positive correlation between days to first heading and to 50 percent flowering with leaf resistance.

A careful analysis of the data in Table 5 supports the concept of using Pressure Bomb technique for assessing the leaf moisture status. The Pressure Bomb technique is the most direct method of assessing plant-water status. This technique is a destructive method and can only

Table 4. Efficiency of transpiration.

Treatments	3rd week		4th week		5th week		6th week		12th week	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
1. Flooded	0.007	0.011	0.097	0.109	0.037	0.042	0.081	0.099	0.228	0.326
2. Saturated	0.014	0.013	0.075	0.099	0.037	0.049	0.064	0.116	0.230	0.278
3. Zero suction	0.014	0.013	0.115	0.099	0.047	0.058	0.082	0.114	0.195	0.235
4. 25-cm suction	0.021	0.018	0.092	0.090	0.059	0.058	0.097	0.107	0.205	0.227
5. 50-cm suction	0.021	0.022	0.093	0.101	0.054	0.053	0.108	0.110	0.236	0.251
6. 75-cm suction	0.035	0.027	0.084	0.120	0.078	0.071	0.121	0.112	0.175	0.263
7. 100-cm suction	0.056	0.055	0.134	0.106	0.068	0.064	0.109	0.122	0.194	0.227
8. 250-cm suction	0.686	0.252	0.163	0.153	0.131	0.116	0.207	0.180	0.267	0.259

Table 5. Correlation coefficient of leaf moisture potential and diffusive resistance to yield and yield parameters.

Parameter	Leaf resistance at panicle initiation	Leaf resistance at 50% flowering	Leaf resistance at grain filling	Leaf moisture potential at 50% flowering	Leaf moisture potential at grain filling
Grain yield	-0.40	-0.31	0.07	-0.37	-0.70
Straw yield	-0.19	-0.17	0.13	-0.43	-0.71
Grains/panicle	-0.14	-0.15	0.18	-0.47	-0.48
Panicles/pot	-0.86	-0.24	0.38	0.27	-0.38
Panicle weight	0.16	-0.08	0.38	-0.41	-0.63
Unit grain weight	-0.12	-0.20	0.40	-0.35	-0.70
Straw weight at mid tillering	-0.17	-0.09	0.40	-0.30	-0.52
Straw weight at grain filling	-0.29	-0.26	0.12	-0.27	-0.61
Days to first heading	0.37	0.35	0.30	0.36	0.23
Days to flowering	0.38	0.47	0.35	0.10	0.04
Tillers/plant	-0.05	-0.21	-0.39	0.30	0.43
Plant height at flowering	-0.14	-0.02	0.36	-0.43	-0.73
Plant height at harvest	-0.11	-0.02	0.36	-0.39	-0.72

be used under field conditions to evaluate the performance of a large number of plant genotypes subjected to similar evaporative demand and a given soil moisture stress.

Discussion

Leaf moisture potential and transpiration rate (i.e. leaf resistance for water loss and transpiration efficiency) vary under different levels of moisture regime at the early stages of growth, but at maturity these remain unaffected by the different moisture treatments.

These observations suggest that the processes of metabolic rates are most affected by moisture stress during the active growing period of the rice plant. At maturity, the moisture stress effects on leaf moisture potential and transpiration rates are negligible.

The leaf moisture potential and leaf resistance measured at initial flowering and panicle development stage are significantly (negative) correlated with grain yield. This indicates that moisture stress is critical during those phases of development.

There are significant varietal differences amongst IR-20 and OS-6 in terms of their leaf diffusive resistance and leaf moisture potential, particularly at modest levels of moisture stress e.g. 50 to 100 cm of water suction. Variety OS-6 had generally more favorable traits at this stress level than IR-20.

The transpiration efficiency of OS-6 is superior to IR-20 at flowering stage, grain filling stage and at maturity. Moreover, the transpiration efficiency of OS-6 is not significantly influenced by soil moisture stress, indicating a greater stability in this comparison of the leaf diffusive resistance and Pressure Bomb measurements in relation to grain yield and overall crop performance. This indicates the superiority of the Pressure Bomb method for screening genotype in terms of their drought tolerance. The Pressure Bomb indicates the energy status of the moisture in the leaves and is not directly influenced by conditions of temperature and humidity. On the other hand, the leaf diffusive resistance is a function of so many other uncontrollable parameters e.g. temperature, humidity, dryness of the leaf etc.

The Pressure Bomb technique can perhaps be further improved by determining the relationship between leaf moisture content and leaf moisture potential e.g. leaf moisture characteristics (similar to soil moisture characteristics). In a clayey soil, the available water holding capacity is greater and inflection point is less sharp than in sandy soil. Similarly, the range of water retention in a drought tolerant variety may be greater than in the drought susceptible variety.

But this analogy should be applied with caution. A vigorously growing plant, with more active metabolic rate, may have lower leaf water potential than stunted plant with no growth. Therefore, comparison of the growth characteristics with the leaf moisture characteristics may provide a better index for screening varieties against drought tolerance.

Varietal selection for drought tolerance can be based on measurements of leaf water potential at a given soil moisture stress. Since leaf rolling and leaf water potential are related, a visual leaf score for the magnitude of leaf rolling can be used as a field criterion for screening germplasm against drought tolerance.

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10. ROOT GROWTH IN RELATION TO SOIL MOISTURE STRESS

Selection of rice varieties for upland conditions should also take into consideration the nature of the root system development of that variety. The desirable root characteristics for upland conditions should consider (i) an extensive deep root system in the initial phases of development so as to avoid dry and hot surface soil, (ii) extensive lateral root system development to help feed and extract moisture from the inter-row zone, (iii) the ratio of root : shoot weight should be high so as to avoid lodging and to enable cover larger soil volume, (iv) the root diameter and the weight per unit length should be larger for upland conditions. A thin and fibrous root system is more desirable for paddy than for upland conditions.

The effect of moisture stress on the root system development of rice is not well understood. It is, however, desirable that a suitable upland variety should develop a deep and extensive root system to combat drought stress. The systematic screening of varieties for their drought tolerance under upland conditions should take into consideration the influence of drought stress on root system development. For example, Jana and Ghildyal (1966) reported that optimum matric potential for the development of radical in rice was 100 millibar (mb). Yamagata (1960) observed that with irrigation, the number of roots was high and the branches developed well. Murthi (1969) reported significant differences in the rate of root elongation of upland and swamp rice varieties.

Fuji (1961) reported that the curvature of the roots growing under upland soil was different from those growing in paddy. Varontsov (1965) observed that submersion had harmful effect on root system development.

Similar results have been reported by Soegima and Kawata (1969). Kawata et al (1964) also compared the root hair development and cell taxonomy of rice varieties grown under upland and paddy conditions and found noticeable differences.

Many scientists have reported that the root system of most of the rice varieties is concentrated in the upper 5 - 10 cm of the soil (Rajagopalan, 1957; Pelerents, 1958; Inforzato, et al 1964). Wu and Lan (1970) reported that 92.1 - 97.5 percent of the roots of six varieties investigated were in the top 20 cm. Kar and Verade (1969) observed the maximum root growth and penetration of rice seedlings grown in cylinders when bulk density and penetration pressure were 1.6 gcm^{-3} and 36 kg cm^{-2}, respectively. Rice root growth under saturated soil conditions was more significantly related to bulk density than to soil strength.

Rice root growth can also be affected by soil moisture stress and soil temperature regimes. Sasaki and Yamazaki (1970) found that the plant height and root development of rice seedlings were positively correlated with the germination rate of the seed at low temperature. Miyasaka (1970) observed that drainage of paddy increased the resistance to root lodging and culm breakage, parameters that are influenced by root development. Kawashima and Tanabe (1972) reported beneficial effects of mulching to the improvements in root devel pment and to the decrease in the number of non-productive tillers. Nicou and Seguy (1970) found that decrease in the bulk density of the surface soil as a result of plowing significantly increased the root system development of upland rice.

Kar et al (1974) related the production of roots under non-submerged conditions to stage of growth and observed that root number and density increased up to maximum tillering. Maurya and Ghildyal (1975) found that the root distribution in the upper 30 cm zone was generally high in upland than in flooded conditions.

Various investigations have also studied the root-shoot ratio of rice as affected by soil moisture stress. Rajagopalan (1957) reported that th root-shoot ratio was greater in upland than lowland conditions. Ota and Lee (1970) reported a significant correlation between root activity at ripening stage with grain yield. This observation can have an important bearing on final grain yield, particularly during the stress conditions. Similar observations had been made by Lee (1972).

Recent investigations on study of root system development of rice varieties have indicated that resistance to drought is closely associated with extensive, and deep root system (Loresto and Chang, 1971; Paningbatan, _et al_ 1975; Parao, _et al_ 1976, and Parao and Cabuslay, 1977).

Root growth studies conducted at IITA in 1973 are presented in the following sections.

Effect of moisture regime on root growth of IR-20 and OS-6.

(i) Root weight:

Root weight was significantly influenced by soil moisture regime and varietal effects.

The wet weight of root decreased exponentially with increase in moisture stress in both varieties. OS-6 had higher root mass than IR-20 for all the moisture regimes investigated. But the relative decline from submerged to saturated soil conditions was only 5 percent in OS-6 compared with 53 percent for IR-20.

The maximum decrease in the root weight of OS-6 occurred as the suction increased from saturation at the surface to saturation at 15-cm depth. The decrease in wet root weight of OS-6 under zero suction at 15-cm depth, compared with that under submergence, was 35 percent, compared with 70 percent in case of IR-20. The subsequent decline in the root weight of both varieties was small. The total wet root mass of OS-6 was [illegible]-6 times higher compared with IR-20 for all soil moisture regimes investigated (Table 2).

Dry root mass of OS-6 and IR-20 is shown in Figures 1 and 2, without and with clearing the additional extraneous material. The dry root mass also follows a pattern similar to the wet root mass. The OS-6 had significantly higher dry root weight at all the moisture regimes compared with IR-20. The relative decline in the root weight of OS-6, as the moisture regime changed from submergence to saturation, was only slight. However, there was a sharp decline in the dry weight of IR-20. The root system of IR-20 is definitely more suited to submerged paddy environments than for drought prone upland conditions.

(ii) Root number. The total root number was also significantly influenced by variety and soil moisture regime (Table 1). The analyses of the number of roots as influenced by soil moisture regime and varietal effect is presented in Table 2. Contrary to the root weight, the number of roots was higher in IR-20 than in OS-6. The differences were particularly high for submerged and saturated soil moisture regimes. The root number in OS-6 for the submerged and saturated moisture regimes was only 67 percent and 80 percent of corresponding root number in IR-20. The relative decline in the total number of roots with increase in suction was considerably more in IR-20, compared with that of OS-6. For soil moisture regime of zero suction at 15-cm depth, the root number of IR-20 had decreased to only 48 percent of submerged treatment. A similar decline for OS-6 was only to 53 percent. The total root number at high soil moisture suction of 250 cm of water was identical in both IR-20 and OS-6.

(iii) Root diameter. Since the root weight of OS-6 is more and the root number is lower than that of IR-20, its root diameter and the weight of a small root section must also be more than that of IR-20 (Table 2). Root diameter of OS-6 was significantly (Table 1) more than that of IR-20 at all the soil moisture regimes investigated. As the soil moisture regime changed from submergence to saturated conditions at the surface, the root diameter of IR-20 decreased by 18 percent, whereas that of OS-6 increased by 9 percent. The root diameter of both varieties decreased as the soil moisture suction increased from saturation at the surface to saturation at 15-cm depth. Larger root diameter of OS-6 than that

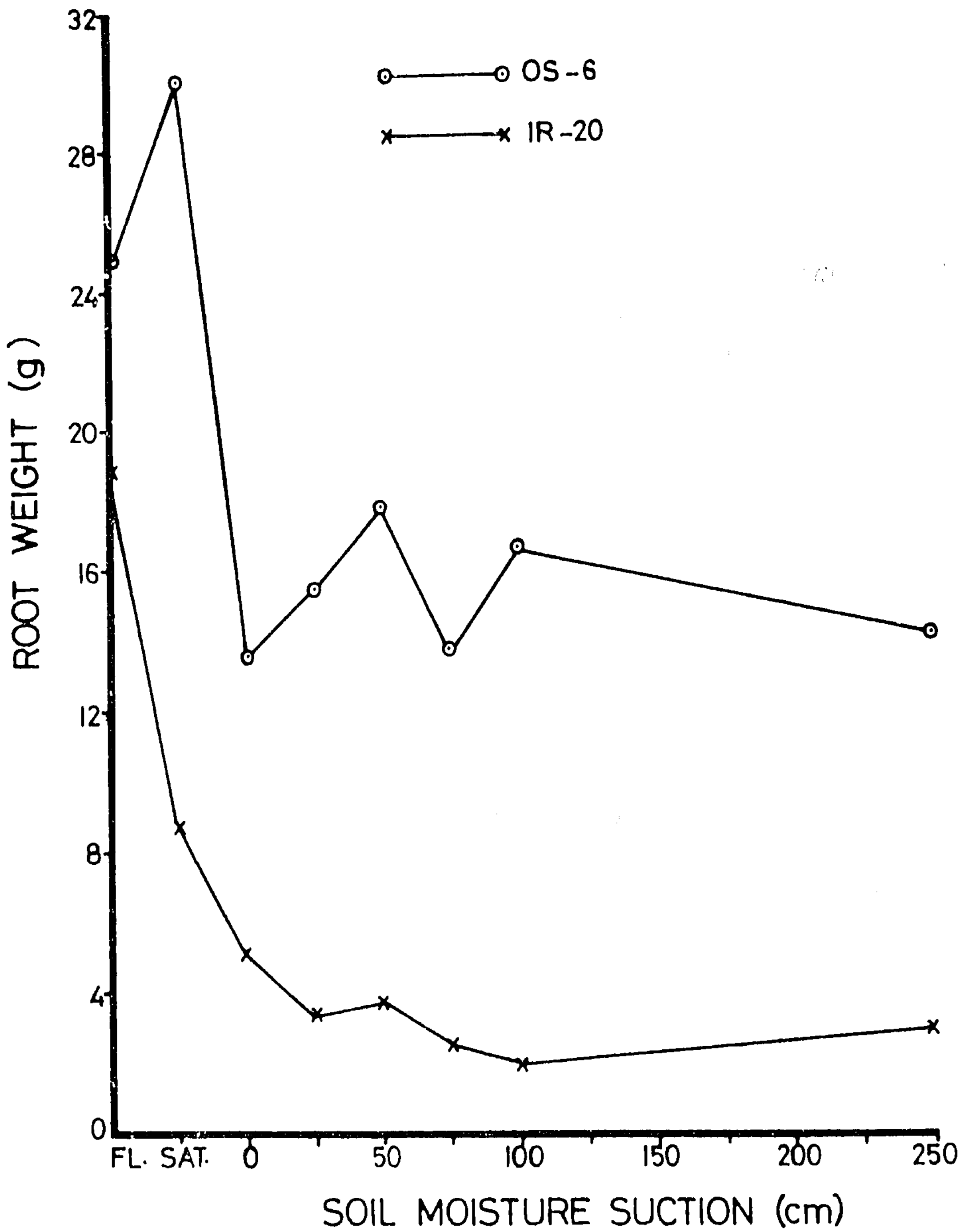

Fig.1. Root dry weight as influenced by the soil moisture regime (without clearing).

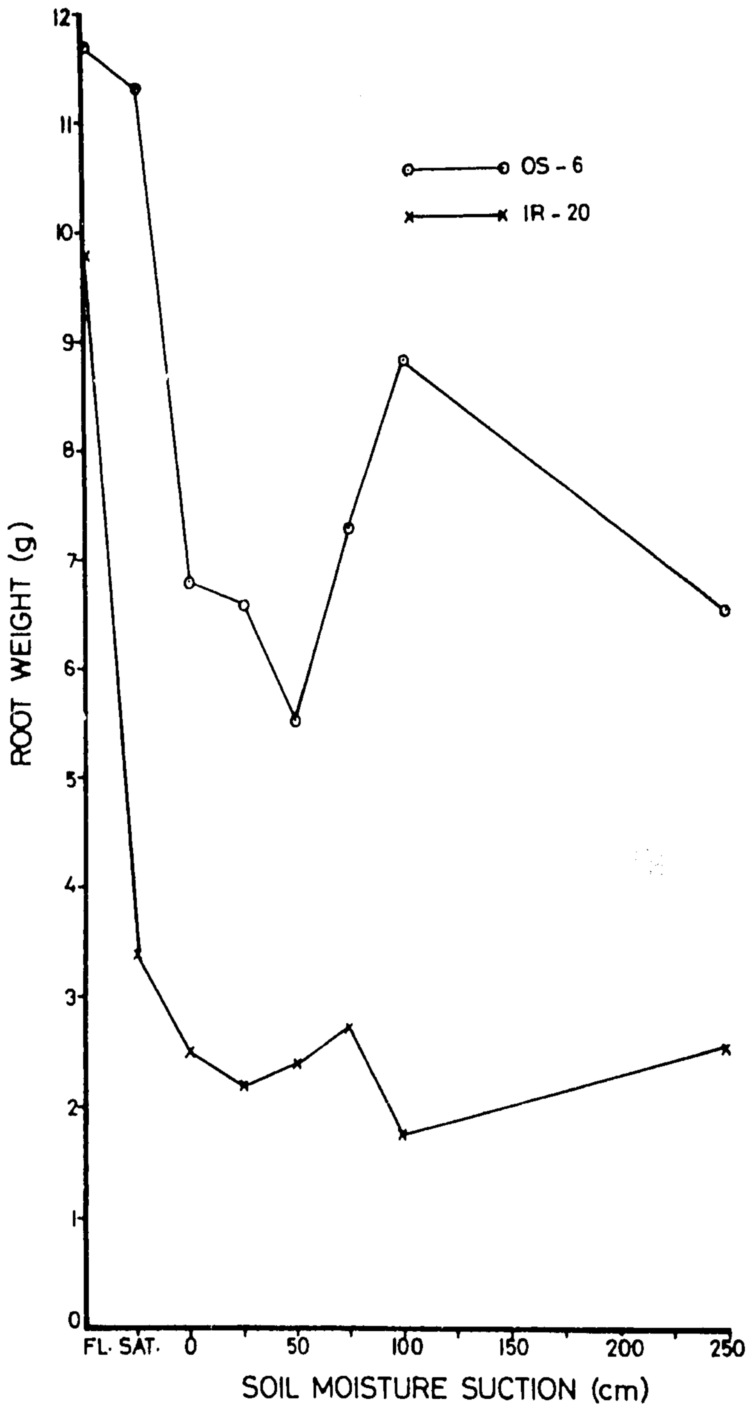

Fig.2. Root dry weight as influenced by the soil moisture regime (after clearing).

Table 1. Analysis of variance of F ratio for the root system development as affected by variety and soil moisture regime.

Source of variation	Wet weight of roots	Dry weight of roots	Root diameter	Root number	Root system area	Root section weight
Variety (V)	41.8**	38.9**	25.9**	5.3*	20.6**	109**
Moisture regime (M)	2.2*	4.7**	2.1	8.8**	2.5*	7.3**
VXM	0.2	0.9	0.6	0.8	1.1	1.1

Table 2. Influence of soil moisture regime on root systems development.

Moisture regime	Root diameter mm		Root wet weight g/plant		Root dry weight g/plant		Root number/ plant		Root system area (cm2)		Weight of 3 cm root section	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submerged	1.28	1.65	59.2	95.5	9.78	11.70	404	[illegible]74	1.45	2.29	0.36	0.85
Saturated	1.05	1.80	28.5	90.0	3.40	11.30	287	209	0.87	2.59	0.36	0.73
Zero suction	1.08	1.29	18.1	61.5	2.50	6.78	173	147	0.69	1.36	0.23	0.50
25-cm suction	1.02	1.18	14.5	52.6	2.23	6.56	189	144	0.84	0.71	0.22	0.42
50-cm suction	0.79	1.29	19.9	66.7	2.41	5.42	171	123	0.54	0.15	0.19	0.43
75-cm suction	0.91	1.30	15.9	62.7	2.74	7.32	150	128	0.69	0.14	0.18	0.48
100-cm suction	0.90	1.42	10.5	66.7	1.75	8.77	118	131	0.67	1.71	0.12	0.48
250-cm suction	0.90	1.18	16.1	55.5	2.51	6.44	113	112	0.68	1.23	0.16	0.49
LSD (.05)	0.17		14.3		1.49		37		0.35		6.20	
LSD (.05)	0.22		19.1		1.99		49		0.46		8.27	
CV (%)	27.9		62.1		51.8		40.1		57.9		31.9	

of IR-20 makes the former variety more suited for upland conditions than that of the latter. A large root diameter enables a deeper penetration through hard and dry soil than fibrous root system.

(iv) Root system area. As one would expect from the comparison of total root weight and the diameter, the root system area of OS-6 was also more than that of IR-20 and it followed a pattern similar to that of root diameter (Table 2).

(v) Weight of 3 - cm root section. Data presented in Table 2 and in Figures 3 and 4 show significant differences (Table 1) in the weight of 3-cm root section due both to varietal differences and to effects attributed to variations in soil moisture regimes. The weight of 3 cm of root section of OS-6 was 2-4 times that of IR-20 at various soil moisture regimes. The varietal differences in weight of 3-cm root section under submergence and optimal moisture regimes were rather small. The differences increased with an increase in moisture stress, and were in favor of OS-6 although the relative decrease in the unit root weight with an increase in moisture stress may not be significantly different in the two varieties investigated.

(vi) Root length. The influence of soil moisture regime on root length of IR-20 and OS-6 is shown in Fig. 5. The root length measured after washing, was significantly more in OS-6, compared with that of IR-20 for all the moisture treatments. The root length of OS-6 was not different at different soil moisture regimes. There was a slight increase in root length with increase in soil moisture suction from zero, 50 and 75 cm, followed by a slight decrease in root length at suction of 250 cm. Root length of IR-20 was the lowest for the submerged and saturated soil treatments, and increased significantly with increase in suction from saturation at the surface to saturation at 15-cm depth. There was no difference in root length of IR-20 at soil moisture regimes of 25, 50, 75, 100 and 250 cm of water suction (Fig. 5).

Root growth and grain and straw yield.

The coefficients of linear correlation between various parameters of root growth described earlier, grain and straw yield at various growth stages, and grain yield parameters are shown in Table 3. Both dry and wet root weights were significantly correlated with grain yield, straw yield, number of grains/panicle, panicle weight, unit grain weight, and with dry matter production at various growth stages. Similar correlations existed with root diameter, root system area, and root section weight. The agronomic importance of total root number in relation to grain and

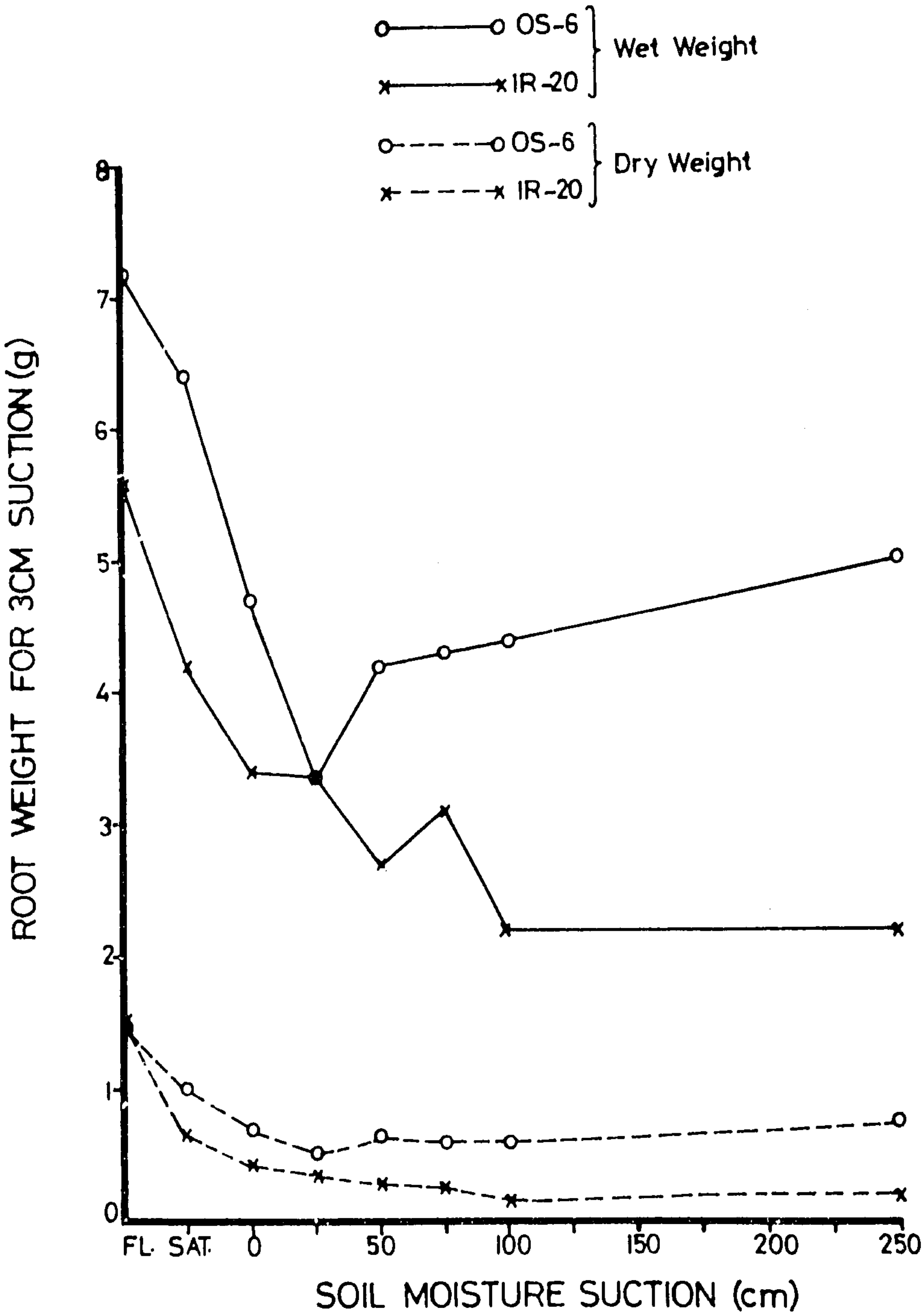

Fig.3. Effect of soil moisture regime on root weight per unit length (without clearing).

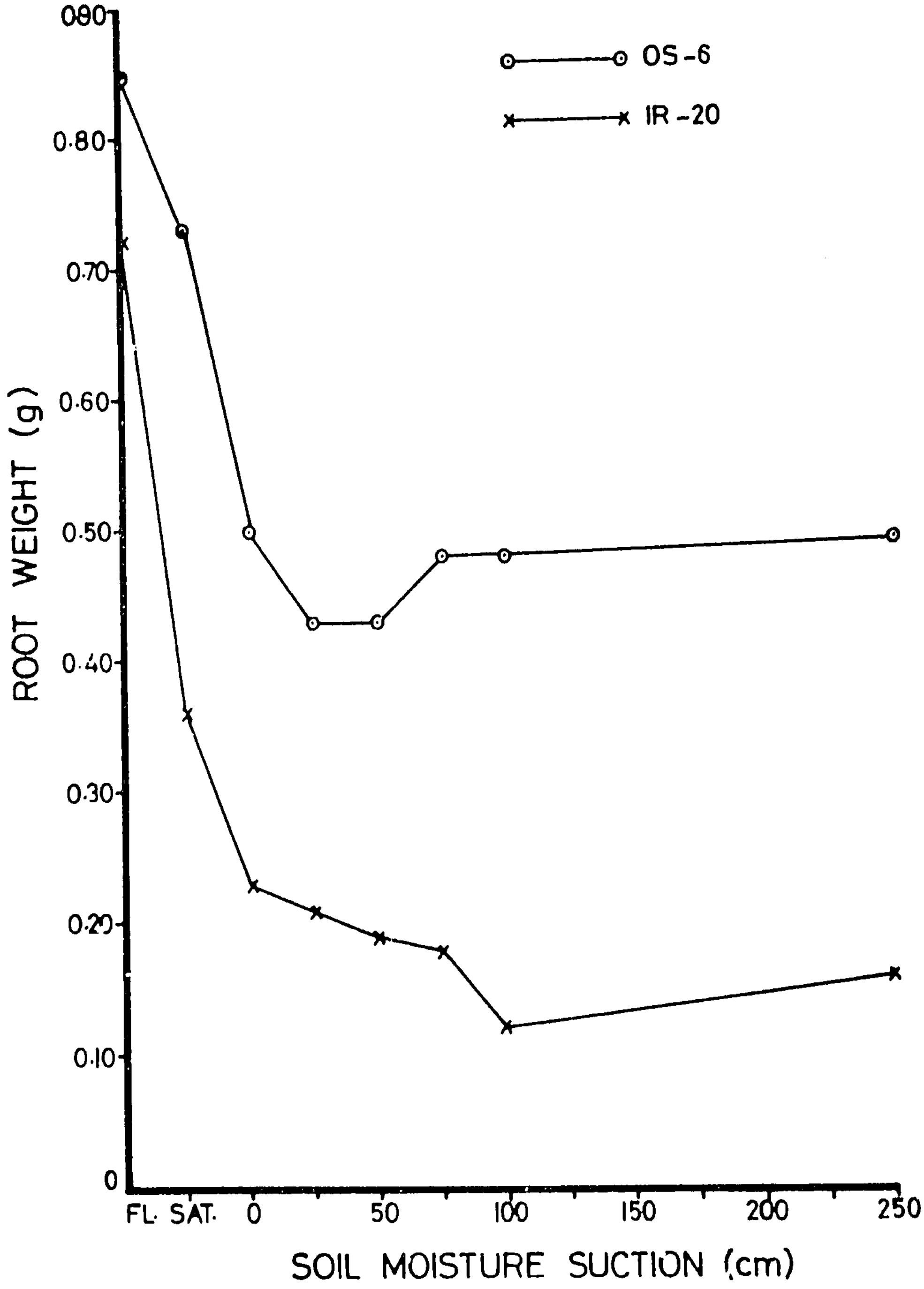

Fig.4. Effect of soil moisture regime on root weight per unit length (after clearing).

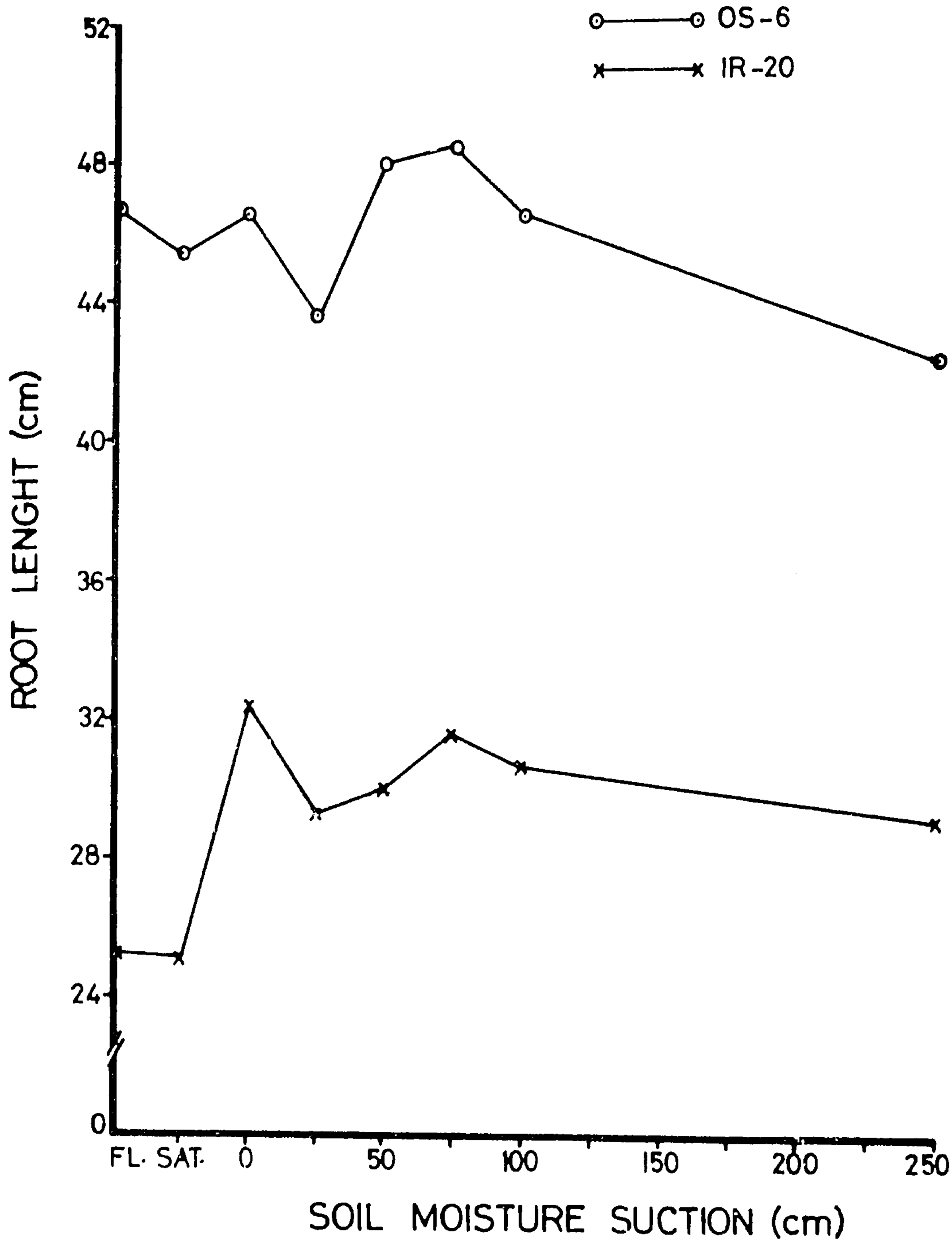

Fig.5 Effect of soil moisture regime on root length.

Table 3. Correlation coefficient of root systems with yield and yield parameters.

Parameter	Root diameter	Root wet weight	Root dry weight	Root number/ plant	Root system area	Root section weight
Grain yield	0.65	0.74	0.76	0.30	0.60	0.69
Straw yield	0.73	0.86	0.85	0.26	0.68	0.86
Grains/panicle	0.43	0.59	0.53	-0.17	0.38	0.56
Panicles/pot	-0.16	-0.21	-0.12	-0.53	-0.13	-0.34
Panicle weight	0.46	0.57	0.54	-0.16	0.42	0.61
Unit grain weight	0.52	0.59	0.53	-0.20	0.45	0.66
Straw weight at mid-tillering	0.56	0.71	0.74	0.16	0.58	0.64
Straw weight at grain filling	0.62	0.66	0.72	0.47	0.63	0.66

straw yield was not significant. The number of panicles was not correlated with any of the root parameters.

The varietal screening for drought tolerance must, therefore, include evaluation of the root system development of these varieties. The important factors include wet and dry root mass, root depth, root surface area, and root diameter. These characteristics are summarized as follows:

Root characteristics for upland conditions

The analysis of results presented in this and previous chapters strongly indicates the following characteristics of OS-6 in favor of IR-20:

(i) Deeper root system,

(ii) Higher total root mass, particularly when grown at high soil moisture stress

(iii) More root diameter,

(iv) Fewer and stronger roots designed for deeper penetration and to prevent lodging,

(v) More cross-section area to come in contact with large root volume,

(iv) Higher root: shoot ratio for better water absorption and uptake.

These are certainly more desirable characteristics for upland conditions. Field experiments conducted on OS-6 both under upland and valley bottom regions support these conclusions. The OS-6 has generally outyielded IR-20 under upland conditions in most of West Africa. Upland varieties should, therefore, be selected for most of these root characteristics mentioned above. The field technique of examining root systems is important in this connection.

Perhaps the mini-rhizotron system developed by Bohm (1976) can be used. This technique has also been used at IITA for investigating tillage influences on root system development and it shows promise.

Conclusion

The upland varieties such as OS-4 and OS-6 have better root system than lowland varieties e.g. IR-20. The root system criteria for screening against drought tolerance consist of deeper root system, more root length per unit weight, continuous development of root system even during flowering and heading stages, and high deep root-to-shoot. These criteria have been found to be correlated with drought resistance as measured by grain yield, and can be used for screening varieties for tolerance to drought stress.

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11. MOISTURE STRESS - FERTILITY INTERACTIONS IN RICE

The influence of soil water stress on growth and development of rice can be significantly influenced by the amount, kind, and method of fertilizer application. A considerable volume of data has been reported in the literature concerning moisture stress-fertility interactions.

Nitrogen and moisture stress:

Enyi (1964 a, b) reported that the number of dead leaves increased with an increase in moisture stress, but decreased with supplementary nitrogen application. De Datta and Zarate (1970) obtained optimum yield under moisture stress by applying high rate of N. Similar results have been reported by Bhattacharya et al (1970), and Ghildyal (1970).

The interaction between soil moisture regimes and levels of nitrogen supply has been investigated by many workers (De Datta et al 1966, De Datta et al 1968, De Datta and Magnaye 1969, De Datta et al 1969, Takyi, 1972, Gupta and Kathavata, 1972). Rao et al (1972) reported that 90 kg N/ha significantly increased grain yield over 60 kg N, but 120 kg N/ha produced no further increase in yield. Lack of response to additional N was attributed to the limited sunshine hours in Kerala, in southern India (Achuthan-Nayar et al 1973). Shinde and Srivastava (1972) compared the influence of continuous submergence with upland conditions at 10 and 100 kg N/ha. The influence of water treatment was significant only at high N level. The highest grain yield and N uptake occurred when submergence was continued from transplanting to flowering or to maximum tillering. Tavia et al (1975) reported an increase in the protein content and a decrease in the ash content of rice plant when grown on soil with pF from 0 to 2.7. Islam and Ullah (1973) reported from pot culture experiment conducted in Bangladesh that high grain yield of rice was associated either with continuous submergence without fertilizer, or when soil moisture was kept at field capacity and when supplementary fertilizer applications were made. They concluded that the benefits of submergence can also be obtained at field capacity by supplying additional N, P, and K. Similar results were reported by Singh and Pal (1973), who reported the highest yield either by continuous submergence from transplanting to maturity, or with 150 kg N/ha and submergence only until 25 DAP, followed by saturated soil conditions for additional 25 days. Terman and Allen (1974) also concluded from their experiments on water management in rice that high rate of N and P are necessary for equivalent rice yields from upland conditions compared with submerged lowland rice.

Apparently from the review of literature presented, soil submergence does improve fertility status, at least for some of the essential nutrient elements. The exact amount and type of various nutrient elements will also depend on the soil type. In general, one may conclude that unsubmerged rice needs higher levels of N than submerged rice, to produce equivalent yields. For nutrient uptake and availability, there also exists a significant interaction of moisture regime with the method of seedbed preparation, whether the seedbed is prepared with or without puddling. Sanchez (1973) concluded that puddling decreased losses of applied N both in field plot and in greenhouse barrel experiments. However, no significant differences were observed amongst puddled and unpuddled soils, either in grain or straw yield or in the uptake of N, P, K, Mn or Si. Contrary to the results of Sanchez, from experiments conducted on the same soil type and under similar climatic conditions (Philippines), De Datta and Karim (1974) reported 2.5 times higher nitrogen efficiency in puddled than in unpuddled soil. The plants grown in nonpuddled soil had less nitrogen content and lower grain yields.

Phosphorus uptake and soil moisture conditions:

Many workers have reported more uptake of P by rice in submerged than in upland conditions. Giordeno and Mortvedt (1972) reported that dry matter production and P uptake were doubled and that Zn uptake was up to five times more in submerged than in upland conditions. Similar results have been reported by Jha et al (1973). Sanchez (1973) also observed that the beneficial effects of flooding varied with the level of available soil P. In soil of high P availability, no differences were observed when rice was grown under continuous submergence, on a partially oxidised profile, or when flooding was delayed from 15 to 35 DAS. Severe drought stress, however, decreased rice growth and P uptake. It was concluded that beneficial effects of flooding on P uptake by rice depend both on the available P level and on the type of water management practiced. Upadhya (1974) did not observed significant differences in P uptake under continuous submergence or with cyclic drainage. Sahu and Misra (1974), and Patel (1975) also reported an increase in P uptake by rice grown under submergence or saturated soil conditions.

Micro-nutrient and soil moisture regime:

The soil moisture regime, degree of saturation, and/or oxidation or reducing conditions in soil growing rice can significantly influence the availability and uptake of micro-nutrients. Giordeno and Mortvedt (1972) reported more recovery of applied Zn from flooded than from moist soil. Zn uptake was five times more under flooded conditions compared to that of moist soil. Gangwar and Mann (1972) also observed that flooding increased the tissue contents of Fe, Mn, and Zn. The uptake of Zn, however, also depends on soil reaction. For example, Wells et al (1973) reported that flooding alkaline soils reduced the availability of native Zn. Seedling chlorosis on flooded soils was attributed to Zn deficiency.

Many workers have reported the influence of flooding on the uptake of other micro-elements. Islam and Islam (1973) reported higher concentration of N, P, K, Ca and Fe in rice plants grown under submerged conditions than at field capacity. Tiller and Wassermann (1973) reported that flooding doubled the total amount of available Mn in all the four soils investigated. They also reported only a slight increase in Zn uptake under flooded conditions. Tavia et al (1974) observed that P, K, Mn and Mg contents in the rice plant decreased with decreasing soil moisture content. Ghoneim et al (1974) also observed that the concentration of Mn in soil and rice plants increased significantly as the period of soil submergence was increased. Singh and Singh (1975) reported higher uptake of Fe and Mn under waterlogged conditions.

Submerging the rice-growing soils either with polluted water, or those soils which release high concentration of organic acids on submergence, can adversely affect rice growth and yield. Tokunaga et al (1971, 1972) reported poor crop growth when rice was irrigated with water polluted with N from industrial plants. Moraes (1973) observed that organic acids produced due to anaerobic conditions in submerged soil could have deleterious effect on rice. Pajanissamy et al (1973) found that increase in the sodium absorption ratio (SAR) levels of the irrigation water considerably decreased growth, grain and straw yields of rice.

The experiments were conducted in the greenhouse during June 30 - October 3, 1973 with the following objectives:

(i) to determine the interaction between moisture regime and levels of N application on rice.

(ii) to determine the differential varietal response of IR-20 and OS-6 to moisture and nitrogen treatments.

The moisture treatments consisted of continuous submergence of 5-cm, 100-cm water suction at 15 cm, and 250-cm suction at 15 cm depth. There were four levels of nitrogen application: 100 ppm, 200 ppm, 300 ppm, and 400 ppm. Nitrogen application was made in the form of $(NH_4)_2SO_4$ with three split applications in the ratio of 30: 30: and 40 percent applied at planting, and at 3- and 6-week stage of growth. The interaction between levels of nitrogen and moisture stress was investigated for both IR-20 and OS-6. Each treatment combination was replicated four times and the containers were distributed in the greenhouse space according to a completely randomized design.

The surface soil from Apomu soil series was packed in containers 35 cm in diameter and 26 cm deep to a bulk density of 1.4 $g\,cm^{-3}$. Soil was packed to 5 cm from the upper edge of the container. The irrigation schedule was regulated through the use of tensiometers installed at 15-cm depth.

Addition of water to the soil was done through subsurface irrigation, facilitated by a perforated tube installed in the center of the drum.

Periodic observations were made for plant height, tiller count, leaf area index at 50 percent flowering, leaf moisture potential and the leaf diffusion rate, dry matter production at various growth stages, and grain yield and yield components.

Various parameters of root growth such as root weight, root length, diameter, etc. were investigated at maturity by carefully washing the roots from the soil in all the treatments. The results are presented below:

Plant height. The influence of soil moisture regimes and nitrogen levels on plant height of IR-20 and OS-6 is shown in Figure 1. The analysis of variance table of F ratio for plant height at various growth stages (Table 1) indicates significant effects of moisture regime, nitrogen levels, variety and the interaction between variety and nitrogen rate for different growth stages. OS-6 significantly grew taller than IR-20 as from 20 DAS. There were no significant differences between M_1 (submergence) and M_2 (100 cm suction) levels of moisture regime, but M_3 treatment (250 cm of water suction) grew the shortest, particularly at the highest rate of N application. High N rate and the highest moisture stress had the most detrimental effect on plant height of both IR-20 and OS-6 (Appendices 1-9). The plant growth and vigor of IR-20 and OS-6 under different moisture regimes and nitrogen levels are shown in Plates 1-18.

Tiller count. Influence of soil moisture regime and nitrogen levels on tiller count was identical to that of plant height (Fig. 2) and Appendices 10-21 . The varietal effects on tiller count were not significant (1% level) until about 60 DAS (Table 2). OS-6 had considerably lesser tiller count than IR-20, for all moisture regimes and levels of nitrogen application. The increase in soil moisture stress significantly increased the tiller production in the two varieties, but the tillers were not all productive. Increase in N rate also increased tiller production. The interactions between moisture regime and variety, and nitrogen level and variety were also significant for the maximum tiller count.

Dry matter production at various growth stages. Table 3 shows the data of dry matter production (shoot only) as influenced by soil moisture regime and level of nitrogen application for both varieties. Detail analysis of dry matter production at various growth stages is shown in Appendices 22 and 27, and in Table 3. Final straw yield increased exponentially with an increase in the rate of N application until 300 ppm N for the submerged moisture regime. There was a decline

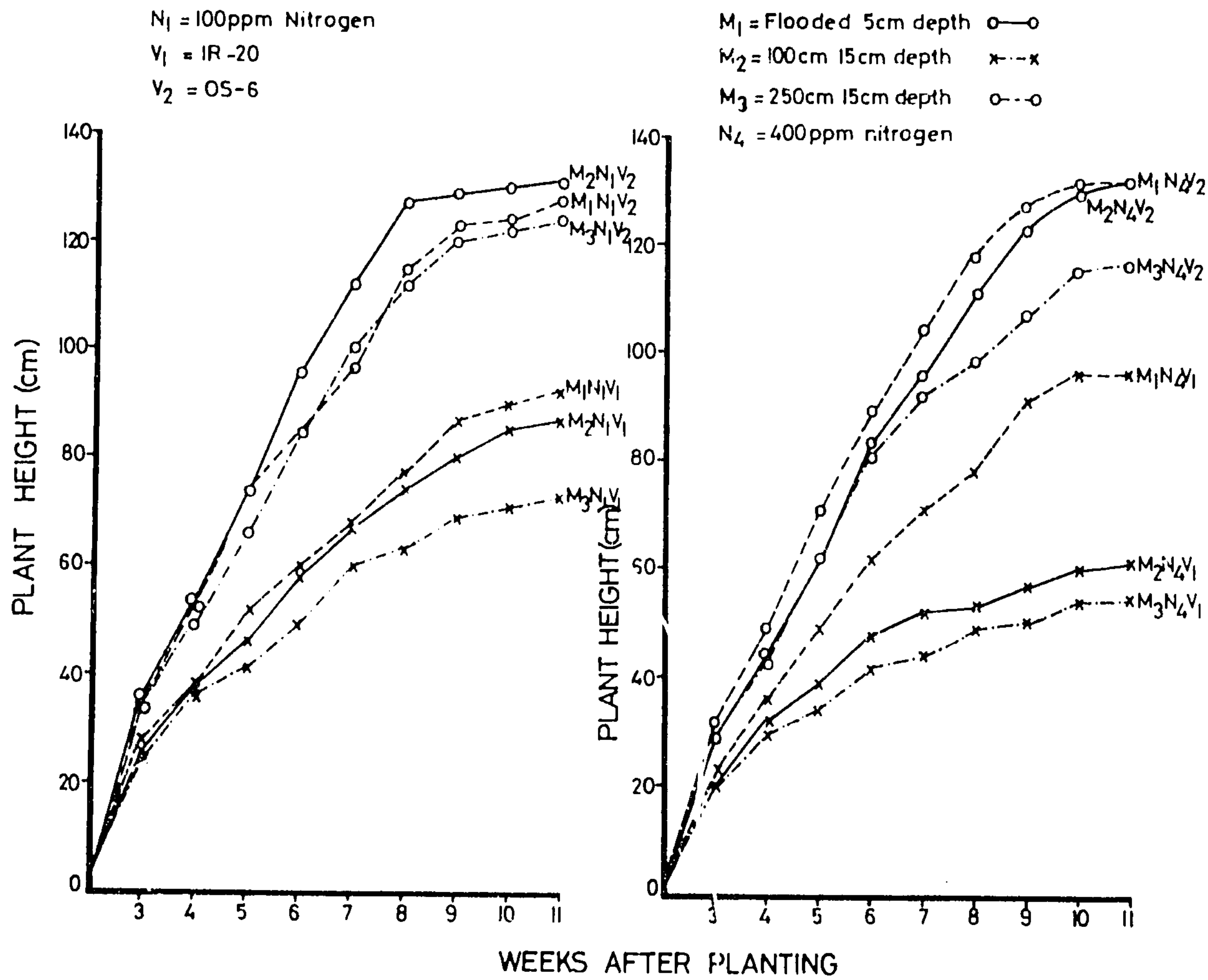

Fig.1. Effect of soil moisture regime and N rate on plant height.

Table 1. Analysis of variance table of F ratio for plant height measurements at various DAS

Source of variation	F. Ratio								
	25	32	39	46	54	62	70	77	110
Moisture (M)	7.72*	69.5**	12.36**	23.1**	87.9**	201.2**	66.6**	82.9**	80.0**
Nitrogen (N)	19.6**	18.1**	11.63**	13.8**	11.8**	15.7**	14.5**	23.6**	16.0**
Variety (V)	321.0**	821.4**	316.0**	967.4**	2101.4**	3306.4**	2189.4**	2858.4**	395.3**
MXN	2.2	2.4	8.2*	9.5*	3.3	5.4*	5.4*	6.6*	11.9**
NXV	0.16	4.5*	13.1**	18.4**	24.8**	64.9**	44.6**	53.1**	13.2**
MXV	0.55	0.55	0.3	2.0	1.1	4.0	3.23*	8.2**	0.3
MXNXV	0.44	0.51	6.7	1.3	1.1	2.5	2.24	3.6*	2.9

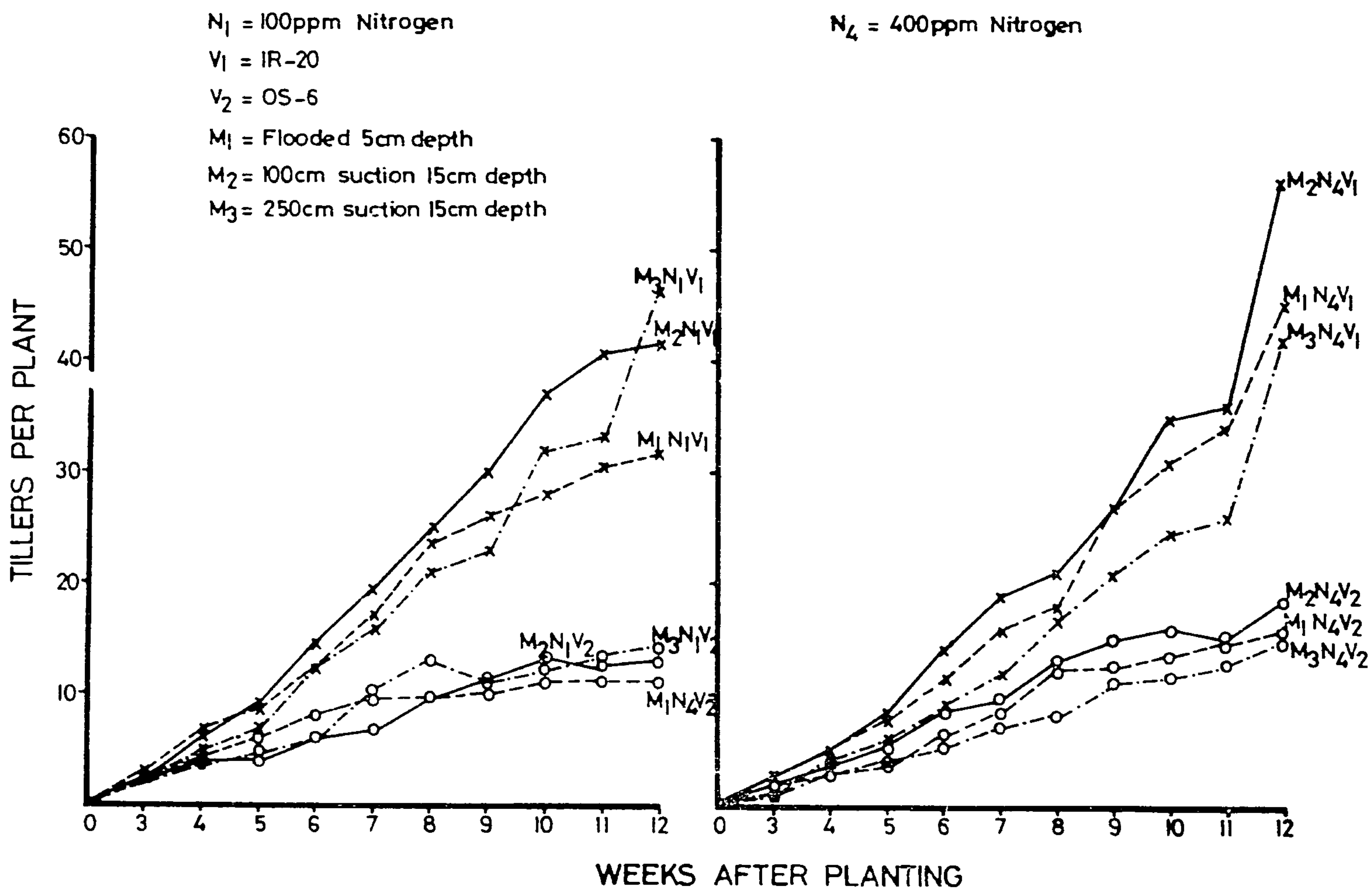

Fig.2. Effect of soil moisture regime and N rate on tiller production.

Table 2. Analysis of variance table of F ratio for tiller count at various growth stages.

Source of variation	F ratio at various DAP									
	18	25	30	38	45	52	59	66	72	95
Moisture (M)	0.79	2.09	11.06*	2.97	7.04*	12.47*	12.40*	47.86**	36.37**	70.82**
Nitrogen rate (N)	4.53*	9.17**	3.02	1.35	2.33	2.91	12.70**	8.35*	12.17**	10.56**
Variety (V)	32.89**	106.73**	173.79**	157.87**	310.37**	294.4**	724.57**	927.25**	699.0**	869.22**
MXN	1.11	1.21	1.96	2.87	3.08	1.23	1.74	4.04	2.37	1.95
NXV	1.47	0.77	0.84	0.19	1.52	0.86	4.11*	11.33**	6.96**	6.65**
MXV	0.61	1.71	1.21	1.35	1.96	4.44*	4.39	2.01	3.92**	3.98*
MXNXV	1.40	0.71	0.86	0.43	0.84	0.80	0.77	0.94	1.00	1.07

Table 3. Analysis of variance of F ratio for dry matter production at various stages of growth (DAS)

Source of variation	F ratio					
	20	40	54	62	90	110
Moisture (M)	0.42	22.34**	26.42**	49.70**	285.07**	28.64**
Nitrogen (N)	1.55	1.31	6.53**	0.95	2.11	17.96**
Variety (V)	0.11	0.13	28.78**	4.39*	8.74*	39.01**
MXN	1.46	1.21	0.95	2.31	3.08	12.28**
NXV	0.27	1.37	2.54	3.15	1.62	1.71
MXV	0.91	0.90	2.41	1.34	2.22	0.98
MXNXV	0.54	0.50	1.88	0.90	1.36	0.64

in the dry matter production for the 400 ppm N rate for both IR-20 and OS-6. The OS-6 had consistently more dry straw weight than IR-20. Nitrogen response for 100-cm suction was identical to that of the submerged treatment, except that the magnitude of increment in straw weight with increase in nitrogen rate was less. There was practically no nitrogen response to straw weight for the soil moisture treatment of 250 cm of water suction.

Grain yield. The influence of cumulative moisture stress (cm-days) on the total grain yield of IR-20 and OS-6 is shown in Figures 3 and 4 respectively. The data indicate some fine points concerning the upland characteristics of OS-6 compared with that of IR-20, and the nitrogen response under upland compared with submerged conditions. Under submerged conditions, the grain yield of IR-20 increased with increasing level of N application. But as the soil moisture stress increased, there was a significant decline in grain yield with increasing level of N application. For the 100-cm suction, the grain yield of IR-20 was in the order of 200 ppm N>100 ppm N>300 ppm N>400 ppm N. For the 250-cm suction, the grain yield of IR-20 was exactly in the order of 100 ppm N>200 ppm N>300 ppm N>400 ppm N. Flooding or submerged conditions were certainly not being compensated for by additional application of N as far as grain yield production potential of IR-20 was concerned.

The yield response of OS-6 at different levels of N application and soil moisture stress was drastically different from that of IR-20 (Fig. 4). Under submerged conditions, the yield of OS-6 levelled off at 300 ppm N. For the 100 ppm N rate, OS-6 maintained a constant grain yield even up to a cumulative soil moisture stress of 24 x 10^3 cm-days. The grain yield of OS-6 was significantly more than that of IR-20 for all nitrogen levels and at medium soil moisture stress (100-cm suction). The N rate of 200 ppm and at the soil moisture regime 100-cm suction produced more grain yield than 100 ppm N under submerged conditions. There were some, though not substantial, beneficial effects of extra nitrogen at low level of soil moisture stress.

Yield components. The influence of soil moisture stress on yield components of IR-20 and OS-6 is shown in Tables 4 and 5. The details and statistical analyses of each of the yield components are presented in Appendices 28-34. Unit grain weight and grain weight/panicle were significantly more for OS-6 than with that of IR-20. Percent floral sterility of OS-6 was higher than that of IR-20 at lower suction, but was reversed at a higher soil moisture stress. Various yield components followed a similar trend to that of grain and straw yield.

Root growth. The data on root weight, root length, root diameter etc, are shown in Tables 6 and 7 and in Appendices 35-39. Under submerged conditions, and for 100-cm moisture suction, dry root weight significantly

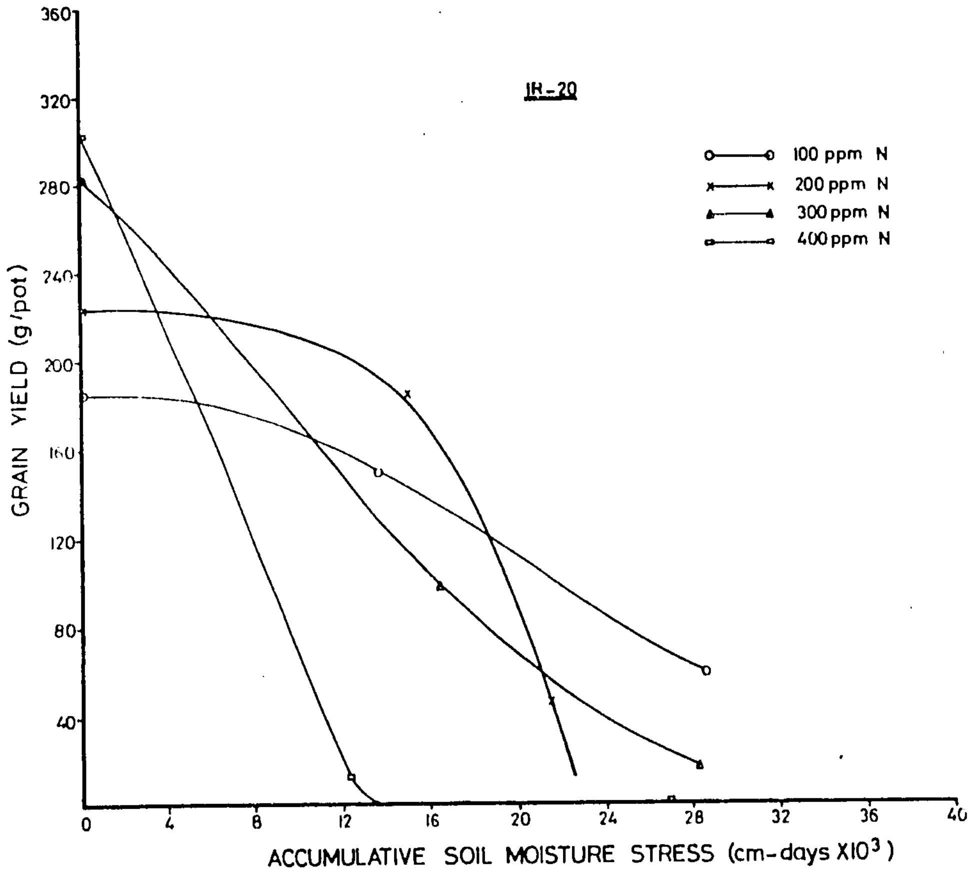

Fig.3 Effect of accumulative soil moisture stress on grain yield of IR-20 for different levels of nitrogen application.

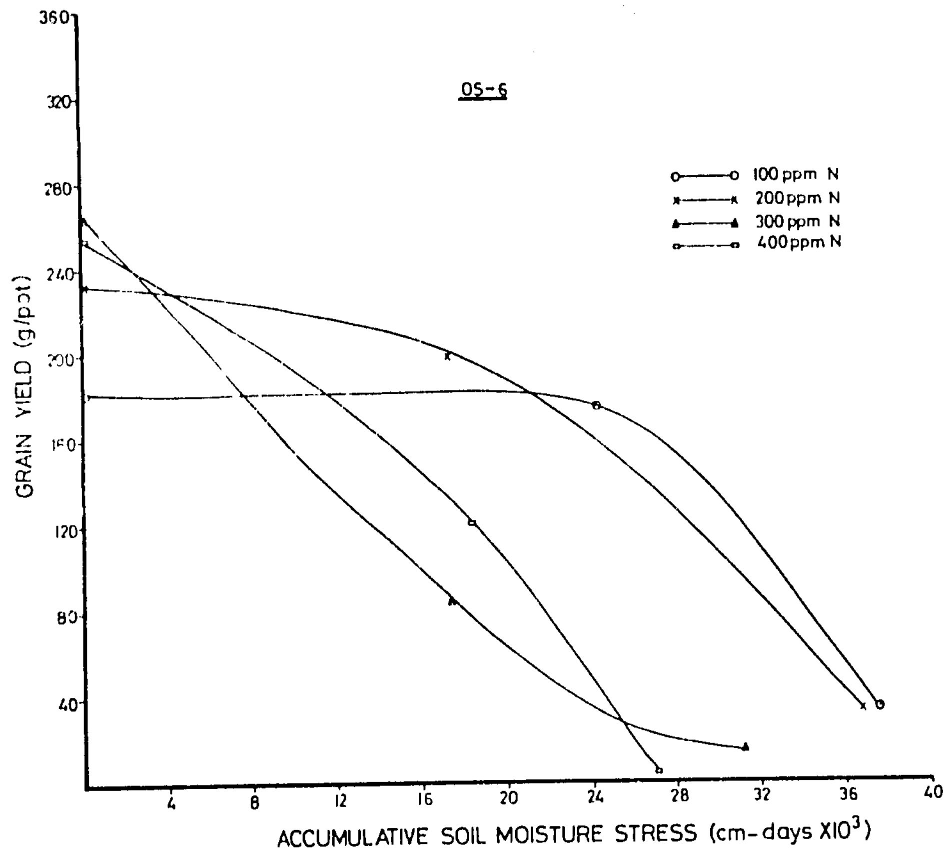

Fig.4. Effect of accumulative soil moisture stress on grain yield of OS-6 for different levels of nitrogen application.

Table 4. Mean yield and yield components of IR-20 and OS-6 under different levels of soil moisture stress and nitrogen levels.

Treatments		100 grains weight		% Sterile florets		No. of Florets/ panicle		% Filled grain/ panicle		Grain weight/ panicle (grains)		Straw yield grain/pot		Grain yield grain/pot	
		IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Flooded 5-cm depth	100 ppm N	1.96	3.63	5.75	7.30	152	156	94.3	92.7	2.98	5.43	97.7	155	186	182
	200 ppm N	1.59	3.54	7.45	10.36	168	157	91.5	89.6	2.92	4.81	222	327	223	232
	300 ppm N	1.91	3.46	6.92	6.83	159	177	93.9	93.6	2.79	4.97	389	518	283	264
	400 ppm N	1.53	3.34	6.61	4.23	135	169	93.4	96.4	2.82	4.95	379	426	303	255
Varietal means		1.75	3.49	6.68	7.07	154	164	93.3	93.2	2.88	5.04	272	357	249	233
100-cm suction 15-cm depth	100 ppm N	1.83	3.43	5.04	12.1	173	147	95.0	88.0	2.48	4.42	210	255	150	176
	200 ppm N	1.86	3.37	5.19	12.6	101	161	92.9	87.4	1.80	4.63	230	421	185	199
	300 ppm N	1.55	1.94	23.2	57.3	70.7	87.7	76.8	42.7	0.84	1.35	272	477	93.9	83.0
	400 ppm N	0.42	3.14	57.0	32.5	42.3	120	43.0	67.5	0.26	2.40	196	427	13.9	121
Varietal means		1.42	2.97	22.6	28.6	96.9	129.2	76.92	71.4	1.34	3.20	227	395	112	145
250-cm suction 15-cm depth	100 ppm N	1.47	2.93	42.1	29.9	83.3	102	57.9	70.1	0.74	1.74	166	268	60.0	54.0
	200 ppm N	0.91	1.02	50.7	72.3	61.7	74.3	49.3	27.7	0.45	0.88	173	327	47.8	33.1
	300 ppm N	0.44	0.90	70.9	76.2	66.3	67.0	29.1	23.8	0.62	0.60	164	270	16.2	15.0
	400 ppm N	0.00	0.00	100.0	100.0	0.00	18.7	0.00	15.3	0.00	0.09	69.0	129	0.00	5.07
Varietal means		0.70	1.21	65.9	69.6	52.8	65.5	34.1	30.4	0.45	0.83	143	249	31.0	26.8
LSD 05	ABC	1.11		27.7		42.3		19.1		0.92		137		39.9	
	A	0.51		17.4		16.3		13.1		0.48		45.0		20.7	
	B	0.58		2.37		22.3		11.6		0.27		49.5		11.5	
	C	0.32		7.99		12.2		5.52		0.26		39.5		27.6	
	CV	34.25		62.0		22.7		17.1		23.9		29.6		17.8	

Table 5. Analysis of variance table of F ratio for yield and yield components.

Source of variation	Grain yield	Unit grain weight	No. of filled grains	Panicle weight	Sterile grains/ panicle	Panicle length	Grain weight per panicle	Days to first heading	Days to maturity
Moisture (M)	228.1**	34.37**	112.0**	49.6**	41.2**	31.2**	592.5**	157.58**	1117.7**
Nitrogen (N)	5.1**	8.22**	10.9**	1.6	3.35**	15.3*	13.2**	95.53**	35.95**
Variety (V)	0.6	66.77**	1.4	0.9	9.8**	6.3*	128.8**	20.70**	40.43**
MXN	18.12**	2.31	3.9*	0.5	4.01**	9.4**	5.0*	26.70**	10.35**
NXV	6.8**	6.13*	0.3	0.03	2.7	0.5	18.3**	0.75	5.12*
MXV	1.5	1.30	3.7*	1.0	0.9	1.6	2.5	1.84	0.77
MXNXV	3.9*	1.74	2.7	1.14	1.1	0.8	1.8	1.36	4.80**

Table 6. Influence of soil moisture stress on root growth.

Treatments		Root length (cm)		Root diameter (cm)		Root dry weight g/plant		Root number		Height at harvest (cm)		Days to 1st heading	
		IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
	100 ppm N	33.5	54.9	1.97	2.23	40.6	36.3	722	537	91.7	128	81.3	78.3
	200 ppm N	38.8	56.6	1.93	2.63	56.0	58.9	976	853	78.3	137	84.3	80.3
	300 ppm N	40.2	49.6	2.73	3.07	66.1	73.4	756	722	93.3	132	88.3	82.0
	400 ppm N	36.0	59.6	2.40	2.23	84.7	42.9	825	891	96.0	132	88.3	82.7
Varietal means		37.1	55.2	2.26	2.54	61.8	530	820	751	94.8	132	85.6	80.8
	100 ppm N	32.0	35.6	1.50	1.93	17.8	17.5	470	693	86.7	131	89.3	83.7
	200 ppm N	35.1	38.4	2.20	2.17	15.9	45.4	486	310	83.0	141	90.0	87.3
	300 ppm N	38.8	53.8	2.13	2.37	59.5	69.3	649	654	82.0	134	97.0	94.0
	400 ppm N	36.6	46.8	1.57	2.03	15.1	33.7	230	492	61.0	132	111.3	89.3
Varietal means		35.6	43.7	1.85	2.13	27.1	41.4	459	537	78.3	135	96.9	88.6
	100 ppm N	54.0	51.4	2.07	2.47	20.1	52.3	541	65.3	72.7	124	101	92.7
	200 ppm N	44.3	49.5	1.93	2.47	18.0	65.8	716	501	66.7	131	107	102
	300 ppm N	39.0	44.7	1.60	2.30	16.2	27.6	504	739	67.3	127	108	107
	400 ppm N	17.6	38.6	1.17	1.70	6.6	13.7	309	313	54.0	116	137	131
Varietal means		38.7	46.1	1.69	2.23	15.3	39.9	518	559	65.2	125	113	108
LSD	AxBxC	18.9		0.64		37.8		420		6.81		9.47	
	A	7.67		0.38		15.8		198		2.80		2.47	
	B	7.15		0.43		20.2		243		4.05		4.37	
	C	5.47		0.18		10.9		121		1.97		2.73	
	CV	26.3		17.9		56.4		41.1		3.85		5.88	

Table 7. Analysis of variance table of "F" ratio for root growth.

Source of variation	F ratio				
	Root length	Root diameter	Dry root weight	Weight of 3-cm section	Root number
Moisture (M)	3.2	4.96*	9.25*	15.73**	6.36
Nitrogen (N)	0.9	3.13	3.44*	1.08	1.09
Variety (V)	17.6**	16.78**	3.61	2.67	0.06
MXN	3.17*	1.87	3.11	1.12	1.63
NXV	1.70	0.95	3.52*	11.75**	0.55
MXV	0.84	0.12	1.54	1.50	1.15
MXNXV	0.57	0.94	0.75	1.65	0.50

increased with an increase in nitrogen application up to 300 ppm N. There was a significant decrease in dry root weight at 400 ppm of N. There was no response to N application for dry root weight at soil moisture suction of 250 cm. Root number was drastically decreased by an increase in the moisture stress. The total root number of IR-20 was 820, 459, and 518, respectively, for submerged, 100-cm suction, and for 250-cm suction. There was a similar effect on the root number of OS-6 (Table 6). Mean root diameter of OS-6 was consistently greater than that of IR-20 at all levels of moisture stress and nitrogen application. There was an increase in root diameter with an increase in nitrogen rate up to 300 ppm, followed by a slight decrease in diameter at 400 ppm N.

Leaf moisture potential and leaf diffusive resistance. The influence of soil moisture regime on leaf diffusive resistance and on leaf water potential at different times during the day is shown in Tables 8 and 9 and in Appendices 40-50. Even in the morning during low evaporative demand, the leaf water potential decreased with increasing moisture stress. Leaf water potential of IR-20 was lower (more negative) than that of OS-6, particularly at high moisture stress. Nitrogen application decreased leaf water potential at 250 cm of water suction, but increased it for the submerged treatment.

Contrary to leaf water potential, the diffusive resistance of OS-6 was greater than that of IR-20. The diffusive resistance also increased with an increase in moisture stress. High nitrogen application rate increased leaf diffusive resistance.

Therefore, OS-6 maintains turgid leaves even at high soil moisture stress, and its diffusive resistance to water loss is greater than that of IR-20. These characteristics of OS-6 are important for upland conditions.

General Discussions

The data presented in previous sections confirm that there exists an interaction between moisture regimes and fertility levels. In upland conditions, the optimum rate of nitrogen application is lower than that in submerged conditions. For IR-20, there is no real substitute for submergence or conditions of saturated soil moisture regime. On the contrary, OS-6 produced more yield at a moderate level of moisture stress by additional application of N. This indicates a different drought escape mechanism for OS-6 than for IR-20.

The OS-6 variety has most desirable qualities for upland conditions. At the lowest level of nitrogen, the yield of OS-6 did not decrease up to 100 cm of water suction, while that of IR-20 declined exponentially with an increase in soil moisture stress. Because of the better root system and differences in leaf anatomy, OS-6 has lower leaf water potential and

Table 8. Leaf resistance and leaf water potential.

Source of variation	Leaf resistance		Leaf moisture potential at 50% flowering			Leaf moisture potential at grain/filling		
	Panicle initiation	Mid-tillering	0800	1100	1400	0800	1100	1400
Moisture (M)	5.72	2.89	0.42	1.62	2.46	26.74**	24.68**	43.78**
Nitrogen (N)	5.33**	4.58*	9.66**	11.24**	12.17**	5.31**	5.24*	7.74**
Variety (V)	0.09	2.68	9.74**	3.76	1.42	0.91	0.44	3.06
MXN	4.95**	3.17*	4.01**	4.22**	3.96*	2.57	2.14	2.68
NXV	4.04*	2.88	5.46*	7.15**	6.24**	0.61	0.53	1.39
MXV	3.12*	5.38**	2.38	1.26	1.47	1.32	1.56	0.69
MXNXV	2.37	5.06**	4.14**	4.70**	4.69**	1.20	1.15	0.54

Table 9. Leaf water potential of IR-20 and OS-6 (PSI).

Treatments		Leaf potential 50% flowering		Leaf resistance 50% flowering cm Sec^{-1}		Total water Added/pot cm/pot	
		IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Flooded 5-cm depth	100 ppm N	295	247	4.18	5.45	208	194
	200 ppm N	267	245	3.94	4.89	254	242
	300 ppm N	250	234	4.38	4.34	329	289
	400 ppm N	294	220	3.61	1.28	329	311
Varietal means		277	237	4.03	4.74	280	259
100-cm suction 15-cm depth	100 ppm N	257	229	5.24	5.49	196	191
	200 ppm N	299	210	4.80	3.77	225	278
	300 ppm N	280	295	4.98	6.42	219	303
	400 ppm N	335	262	5.32	6.21	129	250
Varietal means		294	249	5.09	5.46	192	255
250-cm suction 15-cm depth	100 ppm N	307	235	14.0	7.66	138	199
	200 ppm N	329	287	12.6	13.6	127	209
	300 ppm N	359	277	12.9	6.15	116	143
	400 ppm N	415	390	21.0	10.6	52.1	84.4
Varietal means		353	297	15.1	9.08	108	159

higher diffusive resistance than IR-20. The root system of OS-6 is also thicker, deeper and more voluminous than IR-20 and these characteristics enable this variety to withstand moderate drought conditions and produce economical yields where IR-20 cannot.

The placement of N fertilizers at 10-cm depth is generally superior to broadcast application. In upland conditions, with moisture stress, better fertilizer efficiency at high levels of input can only be obtained by assured water supply through supplementary irrigation or better soil and water conservation and management systems.

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12. SCREENING RICE VARIETIES FOR DROUGHT TOLERANCE

Some of the methods of screening varieties for tolerance to drought stress have been described by De Datta et al (1972, 1975). One of the important criteria is the leaf water potential and the leaf diffusive resistance of a variety. Truly, upland varieties maintain a higher leaf water potential and higher leaf diffusive resistance when subjected to moderate soil moisture stress than those varieties better adapted for submerged culture. There are a lot of physiological and metabolic processes that are directly and indirectly affected by leaf moisture potential, and thus the latter can have a significant influence on growth, development and yield of rice. Even if the soil and environmental conditions (including moisture regime and factors affecting it) are identical, leaf moisture potential of a variety then depends on its root system development and the leaf characteristics. The leaf characteristics important to maintain high moisture potential and high diffusive resistance are: presence or absence of cuticle, leaf hair, and stomatal aperture and stomatal behavior. From the point of view of physiological response, harvest index can also be an important criterion for selecting variety against drought stress. Root characteristics desirable for upland conditions have already been described in Chapter 10.

An experiment was conducted at IITA in the greenhouse in 1974 to investigate plant height, growth, diffusive resistance, leaf moisture potential, grain yield, straw yield, and root development of 20 varieties grown under similar conditions of drought stress.

Twenty rice varieties were grown in 5-gallon containers packed with surface soil of Apomu series at a bulk density of 1.4 gcm^{-3}. Soil moisture suction of 100 cm at 15-cm depth was regulated by the use of tensiometers. A known quantity of irrigation water was applied in accordance with tensiometric measurements. Tensiometric observations were made three times a day, and irrigation water was applied through a sub-surface perforated irrigation tube positioned in the center of the container. A uniform application of nitrogenous fertilizer was made at the rate of 200 ppm, in three split dose applications. Details of the procedure have been described before.

Rice seeds were planted on 7 February, 1974, in containers already maintained at a soil moisture suction of about 100 cm at 15-cm depth. Seedlings were thinned to four per pot, one week after emergence.

Periodic observations were made for plant height, leaf moisture potential, and leaf diffusive resistance. The daily consumptive water use for each variety was carefully monitored. Yield and yield parameters, and root growth were monitored at harvest.

<u>Consumptive water use and days to maturity</u>. Table 1 shows the consumptive water use and the number of days to maturity. There are few varieties which used less than 100 cm of water in their growth period. There are no significant differences among varieties toward the number of days to maturity. Most of them required 120-140 days from planting to harvest.

<u>Yield and yield components</u>. Data shown in Table 2 indicate significant varietal differences in grain yield, yield per unit quantity of water used, panicle length, grains/panicle, unit grain weight, floral sterility and final plant height at harvest. The data on total grain yield and the yield per unit quantity of water consumed clearly distinguish some varieties from the others. Here, varieties K and N are superior to any other variety tested. Higher yield/cm of water used in these two varieties also corresponds with other favorable characteristics such as high number of grains/panicle, high unit grain weight, low floral sterility, and low- to-medium plant height (Table 2).

It is interesting to observe that grain yield was significantly related to the number of grains/panicle, unit grain weight, and floral sterility (negative) as shown by the data presented in Table 3.

<u>Dry matter production at different growth stages</u>. The data shown in Table 4 indicate significant differences in the straw weight produced at different growth stages in various varieties. Both wet and dry straw weights of varieties K and N are lower than the other varieties tested. Though the dry straw weight at harvest is lower, the dry weight at other stages is not. This implies that these two varieties K and N are more efficient than the others in transplanting dry matter into grains. The harvest index of varieties K, N, P and S is superior to others and is above 1.5.

<u>Leaf water potential and leaf diffusive resistance</u>: The data on leaf water potential measured at 50% flowering, grain filling, and maturity stages of growth are shown in Table 5. The leaf water potential of varieties K, N and S has been high (less negative) regardless of high soil moisture suction. Similar data for leaf diffusive resistance are shown in Table 6. During high evaporative demand (1400 hour), the leaf diffusive resistance of both varieties K and N is generally greater than other varieties. This was particularly true during the flowering stage of crop development.

Table 1. Total consumptive water use (cm/growing season) and days to maturity.

Variety code	Accession number	Consumptive water use (cm)	Days to maturity
A	Tox 7-3-8-2-1	93.7	131
B	Tox 7-3-15-7-2	94.1	138
C	Tox 7-4-2-5-2	85.3	138
D	Tox 7-3-3-4-B_1	91.9	138
E	Tox 7-3-5-8-B_1	115.2	138
F	Tox 7-3-15-3-B_1	97.4	119
G	Tox 7-3-4-10-B_1	91.2	138
H	Tox 7-4-2-1-B_1	126.1	138
I	Tox 7-3-5-B_1-B_1	108.1	131
J	Tox 7-3-15-6-B_1	85.3	138
K	Tox 7-3-18-6-B	97.0	138
L	Tox 7-3-11-8-B	105.3	138
M	Tox 7-2-4-3-B	103.5	138
N	Tox 7-3-16-6-B_2	99.1	131
O	Tox 7-3-11-6-B_2	97.4	138
P	Tox 7-3-2-9-B_2	97.1	138
Q	Tox 7-3-16-3-B_2	101.8	131
R	Tox 9-3-17-3-B_2	121.4	116
S	Tox 7-3-11-3-B_2	94.4	131
T	Tox 7-2-4-2-B_2	109.3	119
U	OS-6	113.7	138
V	IR-20	133.1	138

Table 2. Grain yield and yield components.

Variety	Grain yield g/pot	Grain yield per cm of water g/cm	Panicle length cm	Grain/ panicle	Unit grain weight g/100	Sterile grains/ panicle
A	38.1	0.41	19.9	102	1.40	62
B	55.7	0.59	22.4	100	1.38	29
C	37.1	0.43	23.7	81	1.91	41
D	26.6	0.29	20.2	99	1.25	50
E	27.4	0.24	23.6	110	1.74	33
F	46.5	0.48	23.5	89	2.02	39
G	40.5	0.44	23.8	98	1.44	38
H	82.2	0.65	25.6	115	2.13	22
I	36.5	0.34	22.2	102	1.47	44
J	13.1	0.15	23.9	119	1.23	56
K	85.5	0.38	20.9	111	2.03	18
L	55.7	0.53	22.2	139	1.73	24
M	54.0	0.52	20.7	112	1.55	40
N	90.2	0.91	21.5	129	2.20	7
O	20.6	0.21	19.2	87	1.42	41
P	57.8	0.60	23.0	85	1.40	40
Q	57.1	0.56	22.1	105	1.82	22
R	77.5	0.64	27.3	143	2.11	18
S	70.5	0.75	20.2	110	1.93	18
T	64.1	0.59	20.5	128	1.67	32
U	75.3	0.66	27.1	91	1.53	38
V	22.1	0.17	25.8	127	1.37	24
Mean	51.5	-	22.6	108.3	1.7	33.5
SD	22.6	-	2.3	17.3	0.30	13.6

Table 3. Regression equations of grain yield with other parameters.

Dependent variable	Independent variable	r	Regression equation
Grain yield	Panicle length	0.07	Y = 35.6 + 0.7x
Grain yield	Grains/panicle	0.53*	Y = -20.8 + 0.71x
Grain yield	Unit grain weight	0.67**	Y = -57.8 + 43.9x
Grain yield	Sterile grain (no)	-0.53*	Y = 53.1 - 0.97x
Grain yield			

Table 4. Dry matter production* at different growth stages (g/plant).

Variety	35 DAP		55 DAP		70 DAP		90 DAP		Harvest (g/pot)	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
A	0.70	0.16	4.34	0.90	16.00	3.83	36.58	8.91	185	49
B	0.88	0.21	4.82	0.99	16.40	3.83	44.79	10.10	214	56
C	0.57	0.15	4.78	0.96	8.49	1.98	24.87	6.82	211	68
D	0.62	0.18	2.63	0.63	7.71	1.97	25.57	6.70	212	57
E	1.54	0.34	8.77	1.81	20.56	4.65	40.48	9.91	254	64
F	1.47	0.31	7.71	1.73	22.35	5.23	51.37	12.48	180	60
G	0.47	0.13	2.75	0.67	7.33	1.77	25.59	5.89	205	55
H	1.71	[illegible]	13.85	2.82	37.66	8.47	72.40	18.20	310	93
I	0.68	0.20	7.52	1.54	22.47	5.11	59.16	13.32	305	78
J	0.59	0.16	4.10	0.92	9.58	2.32	37.37	7.87	189	54
K	1.32	0.31	9.02	1.89	20.72	4.75	62.19	15.55	158	44
L	0.87	0.21	7.92	1.77	15.73	3.70	48.96	11.73	203	52
M	0.57	0.14	3.10	0.67	17.20	3.67	45.71	9.63	216	50
N	1.78	0.36	16.88	3.45	29.60	6.20	76.44	22.44	168	47
O	1.83	0.35	15.91	3.38	22.25	5.22	49.33	12.22	240	59
P	1.49	0.34	10.74	2.23	23.89	5.60	54.38	15.62	179	25
Q	1.10	0.24	10.04	2.06	22.35	5.10	51.48	12.00	210	56
R	1.54	0.36	10.66	2.27	32.80	7.10	81.85	20.00	202	57
S	0.96	0.21	9.28	1.82	21.38	4.46	49.39	11.80	176	45
T	1.45	0.31	8.44	1.65	18.71	3.87	71.31	15.50	190	49
U	1.09	0.25	5.65	1.34	17.16	3.93	59.60	12.88	398	118
V	0.51	0.13	2.95	0.69	9.95	2.58	26.85	6.24	351	97

* Mean of Three replications.

Table 5. Leaf water potential (Bar) and corresponding soil moisture suction (cm)

Variety	50% Flowering stage				Grain filling stage				Maturity			
	1100 hour		1400 hour		1100 hour		1400 hour		1100 hour		1400 hour	
	L_ψ	S_ψ	L_ψ	S_ψ	L_ψ	S_ψ	L_ψ	S_ψ	L_ψ	S_ψ	L_ψ	S_ψ
A	19.52	75	20.19	140	17.83	35	19.52	75	19.18	25	19.85	50
B	17.50	60	19.85	110	17.16	50	19.85	100	17.16	50	21.20	75
C	20.19	50	20.86	100	18.51	60	21.20	110	19.85	55	20.86	100
D	18.17	100	19.52	150	17.83	20	19.52	100	17.50	20	19.85	40
E	19.18	75	19.85	130	17.83	40	19.85	50	18.51	120	19.85	120
F	18.51	75	19.18	170	18.17	110	19.85	140	19.18	50	21.53	140
G	19.18	100	20.52	120	16.49	100	20.19	160	18 84	95	21.53	120
H	19.52	140	20.19	170	17.83	85	19.52	120	17.50	85	19.85	120
I	18.51	75	20.86	100	16.82	20	20.52	50	17.16	25	18.17	120
J	18.19	130	20.52	160	17.83	110	20.19	220	18.84	85	19.52	220
K	18.84	230	22.21	180	17.16	50	20.19	120	16.49	50	17.16	130
L	19.85	60	20.52	280	20.19	20	23.89	25	20.19	60	21.53	180
M	17.16	160	21.53	45	17.50	60	21.87	100	16.15	25	18.84	60
N	19.52	300	20.19	110	17.50	80	18.17	160	17.50	100	19.18	140
O	19.52	50	20.19	100	17.16	50	18.84	100	17.83	20	18.84	25
P	19.52	140	20.86	180	17.50	70	20.19	140	18.17	60	19.85	120
Q	19.19	140	21.87	120	16.82	70	20.86	130	16.82	120	19.85	160
R	19.52	25	20.19	120	17.84	50	23.89	100	19.18	85	20.52	100
S	19.52	110	21.87	120	15.81	70	20.21	120	16.15	100	17.50	120
T	20.86	100	20.86	140	19.85	50	21.20	160	19.18	130	20.19	50
U	20.19	100	20.86	200	17.16	60	20.52	220	18.17	130	19.85	330
V	21.81	100	22.21	75	19.85	25	21.87	50	19.18	60	20.52	400

$L\Psi$ refers to the leaf water potential in bars

$S\Psi$ refers to soil water suction in cm at 15 cm depth.

Table 6. Leaf diffusive resistance (Sec cm^{-1}) and corresponding soil water suction (cm)

Variety	50% Flowering stage						Grain filling stage						Maturity					
	0900		1100		1400		0900		1100		1400		0900		1100		1400	
	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ	L_D	S_Ψ
A	3.34	35	1.81	50	3.21	120	4.37	-	4.23	25	3.33	25	6.24	-	6.85	500	6.99	20
B	3.23	70	2.67	75	3.87	100	4.04	-	4.92	50	2.51	50	7.95	-	8.48	120	5.73	120
C	1.51	100	3.17	50	3.79	25	3.13	-	5.95	45	4.89	45	6.12	-	8.02	120	7.81	70
D	2.25	20	1.68	30	2.85	40	3.01	-	4.02	20	3.29	20	9.07	-	5.98	450	6.89	0
E	2.38	75	1.81	70	3.50	200	3.48	-	4.48	25	2.56	25	5.83	-	4.77	120	5.09	130
F	2.60	75	1.75	90	3.30	100	3.77	-	3.57	75	3.51	75	5.51	-	6.56	60	6.06	140
G	2.11	75	1.67	90	2.72	180	2.62	-	3.51	80	2.87	80	4.98	-	6.50	150	6.05	130
H	2.40	80	1.73	100	2.32	120	3.92	-	3.32	80	3.41	110	4.75	-	5.13	150	7.06	100
I	2.95	105	1.77	120	2.85	140	3.14	-	4.21	25	2.83	25	4.63	-	6.43	100	6.52	160
J	3.18	75	1.68	75	2.45	140	3.77	-	4.42	75	2.93	75	5.17	-	5.69	100	5.23	140
K	2.22	100	1.93	140	3.54	50	2.57	-	3.85	25	2.90	25	6.61	-	10.94	480	5.10	30
L	2.60	75	2.07	110	3.24	150	3.92	-	3.97	20	3.65	20	4.05	-	5.72	120	5.39	100
M	2.43	50	2.30	75	2.76	120	3.42	-	5.15	25	2.41	30	5.52	-	6.04	120	5.40	130
N	2.25	95	1.76	110	2.46	140	3.22	-	4.14	100	2.54	100	4.89	-	5.06	100	6.45	140
O	3.65	55	1.75	60	3.95	120	5.22	-	4.34	25	3.83	30	10.66	-	9.20	320	6.58	0
P	2.95	180	2.05	25	3.01	50	3.15	-	5.00	75	3.29	100	3.83	-	5.90	80	7.57	140
Q	3.73	50	1.52	70	3.79	100	3.71	-	4.31	50	3.38	50	5.23	-	10.10	60	11.55	120
R	4.11	75	2.71	75	3.39	120	3.75	-	3.92	50	3.48	50	5.86	-	8.35	110	6.34	120
S	2.11	80	1.76	90	2.57	130	3.10	-	4.11	50	2.62	50	3.49	-	4.92	60	6.99	100
T	2.90	60	1.68	75	3.20	120	4.36	-	3.78	25	3.34	30	5.20	-	7.78	180	4.85	20
U	2.33	210	2.05	50	2.53	50	3.87	-	4.53	50	3.63	50	4.38	-	4.79	50	6.64	100
V	2.60	25	1.75	30	2.80	70	2.89	-	4.54	130	2.50	25	2.28	-	4.43	25	5.64	45

Conclusions

Some of the desirable characteristics of rice varieties for upland conditions are:

(i) Low consumptive water use

(ii) Low leaf water potential

(iii) High leaf diffusive resistance, and elastic stomatal behavior

(iv) High grain yield/cm of water use

(v) High unit grain weight

(vi) Low floral sterility

(vii) High percentage of grains/panicle

(viii) High harvest index

(iv) Low total leaf area

(x) Better root development.

In addition, the technique of screening rice varieties for drought tolerance described in here can be successfully used for selecting varieties for their drought susceptibility.

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13. PROSPECTS FOR RESEARCH FOR INCREASING RICE PRODUCTION

Demand for rice is on the increase in West Africa. Most of the countries there are now importing a sizeable amount of rice from overseas (USAID, 1968).

Intensification of rice production in West Africa to meet the increase in demand will depend on solving the problems of water management. A satisfactory solution to this problem rests on our scientific knowledge of plant-water requirements for rice under various soils and ecological conditions.

Rice production in West Africa can be expanded rather quickly by developing the soils of valley bottoms. This can be done, no doubt with relatively high initial capital input, for large riverine regions including the Niger valley, the valley of river Senegal and other similar regions. Similarly, large-scale development projects for rice production can be undertaken in the tropics of Latin America in the Amazon region. In addition to these large-scale projects with relatively high initial capital input, small-scale development of valley bottom soils can be undertaken by individual farmers. There is a guaranteed water supply in these valley bottom soils. With the use of improved varieties, adequate nutrient availability, and disease and insect control measures, rice production can be quickly increased by developing these valley bottom soils.

The data presented in this monograph, similar to the conclusions arrived at by other workers, clearly indicates that submergence is not necessary for optimum yield, particularly if these valley bottom soils can be kept at near saturation level. A slight soil moisture stress during the vegetative stage of growth may not substantially affect crop yield and performance. However, an adequate water control system with proper bunding is necessary to alleviate soil moisture stress during periods of drought, and provide drainage when necessary. Fertilizer requirements under submerged conditions may, however, be high for sandy soils which encourage leaching losses. Leaching losses of applied fertilizer on sandy soils are generally high in the initial phases of soil development, but can be minimized with some control on the depth of submergence and on split application of small doses of nitrogenous fertilizers.

The techniques of water management for the valley bottom soils are well known. It is the application of these techniques that require the use of properly guided extension services. One such example is the project "Mesagana 99" successfully launched by the International Rice Research Institute in the Philippines.

In addition to rice production during the normal season, valley bottom soils have adequate water supply in the dry season to enable production of such upland crops as soybean, maize and perhaps vegetables. Some of the crop rotations and cropping sequences for valley bottom soils have been investigated in detail by Moormann et al (1975). These experimental techniques and results need to be verified under other ecological conditions.

The majority of rice production in West Africa at present is under upland conditions (IRRI, 1975). The problems of water management under upland conditions are more severe and complicated than those related to the development of valley bottom soils. There are various interacting factors under upland conditions, including the rainfall amount and its distribution, soil characteristics and the varieties. Nothing much can be done about the precipitation, except that upland rice should be grown in areas where the annual precipitation exceeds evapo-transpiration at least for 6-8 months of the year, and there is a good probability that the number of rainless days during the critical phases of rice development will not be more than 5 to 7.

The soil factors are important. In addition to the fertility status of the soil, selection of suitable soil types must be based on range of soil physical characteristics. These should include texture, moisture retention characteristics, slope, depth of the rooting zone, and the compaction characteristics of the soil. Soils of high-moisture retention capacity, i.e. the available range of water, should be preferred. The rooting depth of at least 30 cm is most desirable. The soils should not be located on the steeper zones of a toposequence.

The selection of suitable varieties is the most important factor in this chain reaction of improving rice production. The selection method used for growing rice varieties under field conditions are not adequate. The variability in tropical soils, even over short distances is too much, and it causes a considerable degree of error in the experimental results. This is true even under dry conditions when a known quantity of irrigation water can be applied in the field. The use of "hydromorphic toposequence" is a better technique only if there can be adequate assessment of soil moisture conditions at different locations along the seepage zone. The seepage zone does fluctuate from season to season and can create an additional variable.

The selection technique described in Chapter 12 of this monograph is adequate, provided care is exercised in monitoring soil moisture regime precisely and in relating crop yield to leaf water potential and leaf diffusive resistance. This technique could be improved to incorporate an automatic irrigation system, similar to the one described by IRRI (1975). There are considerable problems associated with auto-irrigation system in a pot, particularly if the soil moisture stress to be imposed in a sandy soil exceeds 100 cm of water suction. The hydraulic conductivity of soil at higher suction becomes a limiting factor in equitable water distribution in the entire soil mass. Moreover, the roots have a tendency to be concentrated around the ceramic cup, the source of water supply. Roots and the plant are therefore not experiencing the expected stress.

Large containers buried in the soil under field conditions with a plastic roof to prevent rainfall have also been used successfully at IITA (Plate 1). This technique is a good compromise between the field and the greenhouse conditions. The soil mass is larger than most of the pot sizes usually adopted for greenhouse work. The water table depth can be maintained at a desired level throughout the growing period, or for any duration at a given stage of crop growth. The evapo-transpiration can be precisely calculated by calibrating the mariotte bottle used and by keeping the records of daily consumptive water use. Different soil types can also be used for testing the performance of various varieties for soils of different moisture characteristics, nutrient supply or rooting depth (Maurya and Lal, 1977).

A technique which can incorporate a series of constant soil moisture regimes in a large body of soil, and can maintain the desired moisture regime automatically throughout the growth period, is perhaps a better system than any of those described here or in the IRRI manual. A schematic sketch of this system is shown in Fig. 1. To avoid heterogeneity problems, a uniform soil can be packed in a dug-out pit of 3-m diameter and 50 cm deep. A 15-cm wide trench filled with coarse sand can be used as a source of water supply. Change in the depth of water table in this trench will create differential moisture regimes at various points along the radial axis. This technique is generally used by soil physicists in calculating <u>in-situ</u> unsaturated hydraulic conductivity of a soil monolith. If a uniform soil profile can be artificially created, a series of tensiometers or neutron probe access tubes installed at various depths along radial distance will help determine the moisture potention profile at different distances from the free water source. Crop varieties planted along radial axis or along concentric axis in the circle can be grown at a series of constant soil moisture regimes. If the soil moisture characteristics can be precisely monitored, flux measurements can also be made to provide an estimate of evapo-transpiration at various moisture regimes. One can provide a good control on soil moisture regime even next to the water supply by regulating the depth of water in the irrigation canal.

A solution to the problem of water management in rice demands a collaborative effort of soil physicists, plant physiologists, agronomists and plant breeders.

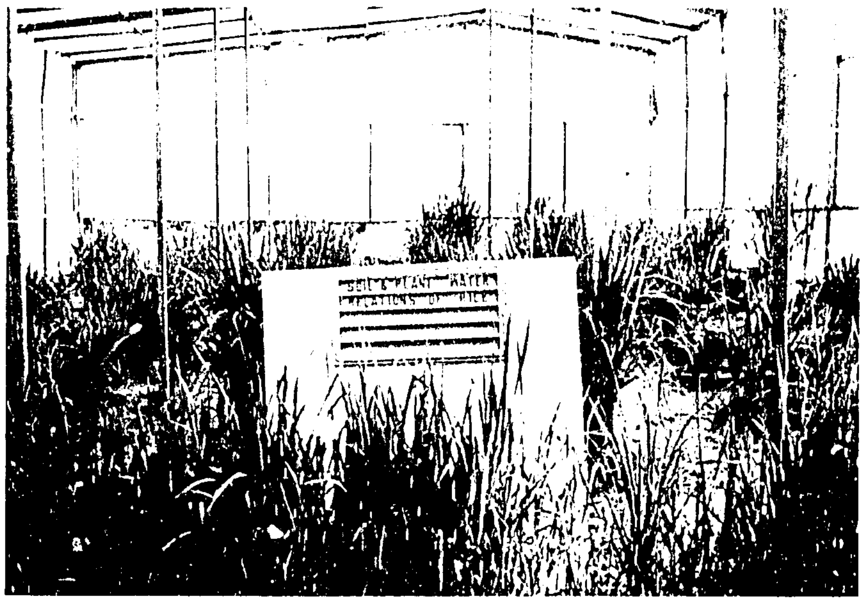

Plate.1. Plastic greenhouse installed over the field lysimetric set up.

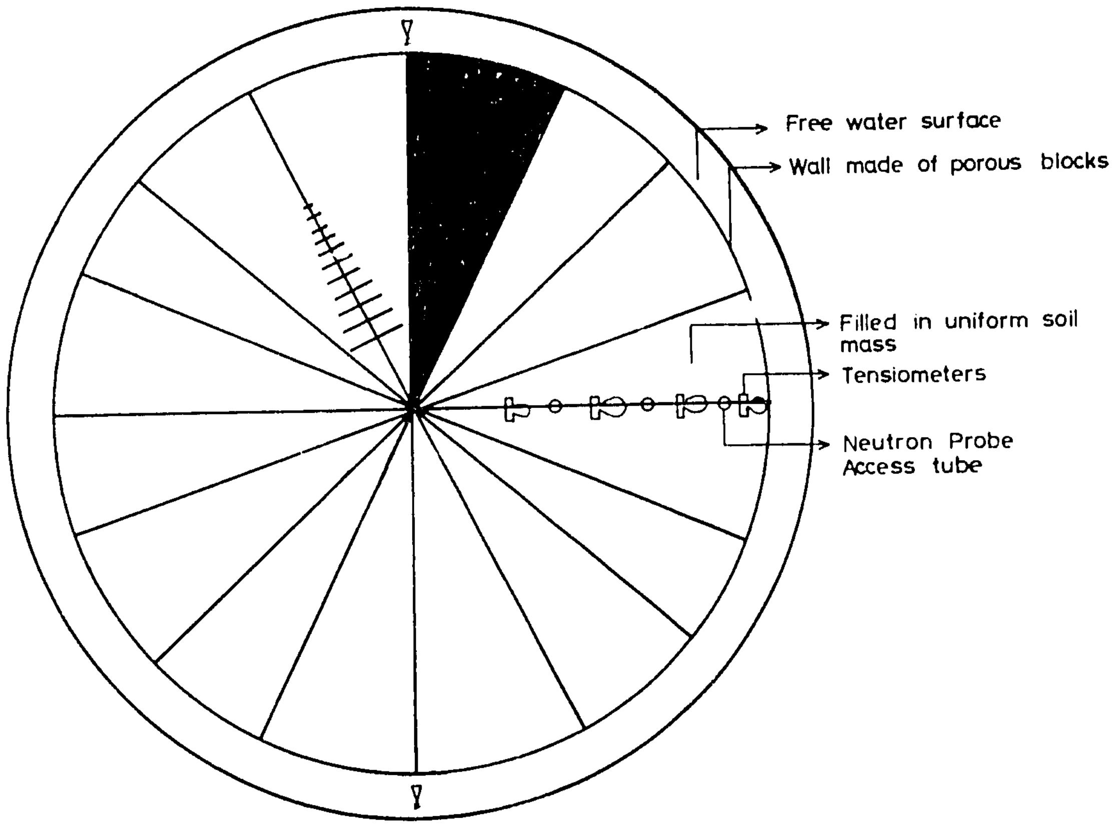

Fig.1. Maintenance of soil moisture regime for screening rice varieties for drought stress.

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APPENDICES FOR CHAPTERS 1 TO 3

Appendix 1a. Chemical analyses of soil sampled from different lysimeters established at IITA, Ibadan.

Lysimeter	pH 1:1 H_2O	E.C. Millimhos/cm 1:2 H_2O	K (ppm)	Ca (ppm)	Na (ppm)
1	6.5	0.11	78	1042	97
2	7.1	0.10	74	422	65
3	6.9	0.10	69	437	66
4	6.6	0.11	52	260	63
5	6.6	0.14	9[illegible]	590	88
6	7.1	0.32	259	606	108
7	6.6	0.12	127	740	78
8	7.0	0.13	124	545	68
9	6.7	0.11	70	480	78
10	6.7	0.13	152	152	78
11	6.7	0.14	130	130	90
12	7.0	0.10	57	57	68
13	7.0	0.11	59	59	68
14	7.0	0.12	93	93	73
15	6.7	0.12	92	92	81
16	6.6	0.12	98	98	85
17	7.1	0.14	109	109	84
18	7.1	0.12	94	94	75

Table 1b. Organic carbon and textural analysis of soil from different lysimeters in rice, established at IITA, Ibadan.

Lysimeter	Organic carbon (t.)	Mechanical analyses		
		Sand	Silt	Clay
1	0.66	32.0	27.64	40.16
2	0.36	75.2	8.64	16.16
3	0.60	70.2	11.64	8.16
4	0.24	75.4	12.44	12.16
5	0.64	64.04	17.16	18.80
6	0.50	66.04	16.80	17.16
7	0.98	59.04	18.80	22.16
8	0.58	60.04	23.16	16.30
9	0.54	64.4	17.44	18.16
10	0.58	63.68	16.72	19.60
11	0.68	63.68	16.72	19.60
12	0.20	67.68	13.00	19.32
13	0.18	66.68	14.72	18.60
14	0.40	68.96	15.08	15.96
15	0.62	68.96	15.08	15.96
16	0.56	66.96	15.44	17.60
17	0.12	62.96	16.44	20.60
18	0.44	68.96	14.44	16.60

Appendix 1. Chemical properties of the surface soil.

Sample Rep.	pH 1:1 H_2O	Conductivity millimho/cm 1:1 H_2O	K^+ (ppm)	Ca^{++} (ppm)	Na^+ (ppm)	Organic carbon %
1	6.3	0.26	105	680	48	1.36
2	6.3	0.28	104	650	46	1.32
3	6.3	0.26	105	690	50	1.36
4	6.3	0.26	107	690	50	1.32
5	6.3	0.26	108	670	48	1.38
6	6.3	0.27	112	664	48	1.34

APPENDIX 2

EXPERIMENTAL METHODS

Evapo-transpiration was monitored using field lysimeters installed within a large paddy field. The height of water in the lysimeter was kept constant by using a mariotte bottle technique involving a 220-liter water tank and a valve to regulate the water supply (Fig. 1). The amount of water (mm) required to maintain a constant water level in 24 hours was recorded as evapo-transpiration.

APPENDIX 3

METHODOLOGY

Effects of submergence treatment imposed at different growth stages:

(Field studies):

These experiments were conducted during May - September, 1971 using open bottom lysimeters installed in a large rice paddy field. These lysimeters were 3 m in diameter and 50 cm deep. Lysimeters were installed by digging narrow circular trenches around a 3-m diameter undisturbed soil monolith. Three of the 18 lysimeter rings were buffered against seepage from outside by a plastic lining up to one meter depth.

The moisture regime under submerged condition was maintained to a depth of 7 cm of water. A still well was installed on one side of the rings to monitor the depth of water in the ring using a Hook Gauge and Vernier scale. The difference in water height on two subsequent days was considered as consumptive water use. The height of the water in the rings was never allowed to fall below 4.5 cm.

For this experiment the following treatments of soil moisture regime were imposed:-

(i) Saturated soil, no submergence

(ii) Submergence from 20 days after planting (DAS)

(iii) Submergence from 35 DAS

(iv) Submergence from 55 DAS

(v) Cyclic submergence of one week with drainage in the following week

(vi) Rainfed.

All treatments were replicated thrice and imposed according to a completely randomized design. Pre-soaked seeds of IR-20 were broadcast in shallow water both inside the lysimeters and the large paddy field simultaneously on May, 1971. Rice was harvested on 23 September, 1971.

The chemical and physical analyses of the soil from each of the lysimeter were done before initiating the experiment, and is shown in Appendices 1a and 1b. The soil texture ranges from sandy clay loam to loamy sand, except soil from lysimeter 1, which has a high clay content. The pH is neutral and salt content is not high.

Sandy coarse textured soil caused high leaching losses of nutrient elements. Consequently the fertilizer application for N were made at frequent intervals. The fertilizer schedule and the amount of fertilizer added was as follows:

Date	Amount of Ammonium sulphate nitrate added per lysimeter (g)
26-5-1971	41 g
10-6-1971	41 g
25-6-1971	100 g
5-7-1971	41 g
7-7-1971	41 g to lysimeter 12 only
14-7-1971	41 g.

Simultaneous applications of nitrogenous fertilizer were also made in the entire field at the same rate as that of the lysimeters. The total amount of nitrogen applied per lysimeter for one crop was equivalent to 120 kg N/ha.

Periodic observations were made for soil moisture potential, plant height, tiller count, dry matter production and nutrient uptake by tissue analysis. Yield and yield components were assessed at maturity. Leaf area was determined by direct measurement using a shape factor of 0.77.

Appendix 3. Evaporation from free water surface in the greenhouse.

Date	Evaporation (mm)	Date	Evaporation (mm)	Date	Evaporation (mm)
25.7.1971	3.12				
28.7.1971	1.04	19.8.1971	0.52	9.9.1971	2.08
29.7.1971	1.04	20.8.1971	3.12	10.9.1971	3.12
30.7.1971	1.04	21.8.1971	5.20	11.9.1971	T
1.8.1971	1.04	22.8.1971	3.12	12.9.1971	4.16
2.8.1971	1.04	23.8.1971	3.12	13.9.1971	3.12
3.8.1971	1.56	24.8.1971	2.10	14.9.1971	2.60
4.8.1971	2.10	25.8.1971	1.04	15.9.1971	3.64
5.8.1971	1.56	26.8.1971	0.52	16.9.1971	T
6.8.1971	0.52	27.8.1971	4.16	17.9.1971	T
7.8.1971	T	28.8.1971	T	18.9.1971	1.04
8.8.1971	2.10	29.8.1971	2.08	19.9.1971	4.16
9.8.1971	0.52	30.8.1971	4.16	20.9.1971	4.16
10.8.1971	T	31.8.1971	2.08	21.9.1971	3.64
11.8.1971	T	1.9.1971	1.04	22.9.1971	2.08
12.8.1971	T	2.9.1971	1.30	23.9.1971	1.04
13.8.1971	T	3.9.1971	2.60	24.9.1971	2.08
14.8.1971	T	4.9.1971	T	25.9.1971	T
15.8.1971	2.60	5.9.1971	3.12	26.9.1971	2.08
16.8.1971	1.04	6.9.1971	2.34	27.9.1971	4.16
17.8.1971	1.56	7.9.1971	0.52	28.9.1971	2.08
18.8.1971	2.10	8.9.1971	1.56		

Appendix 4. Weekly mean relative humidity (%) and temperature (C°) in the greenhouse.

Month	Time	Relative humidity (%)				Air temperature (C)			
		1-7	8-15	16-23	24-30	1-7	8-15	16-20	24-30
May	0800	-	-	83.2	79.1	-	-	21.8	22.8
May	1500	-	-	74.7	69.5	-	-	25.9	29.3
June	0800	78.0	95.3	97.3	98.5	22.1	22.3	21.6	21.8
June	1500	74.0	87.5	70.8	70.1	26.8	26.3	29.0	26.6
July	0800	98.7	96.7	93.0	98.0	22.5	21.2	21.2	22.8
July	1500	73.6	80.9	79.0	87.0	27.9	25.7	24.9	25.8
August	0800	100.0	100.0	95.0	89.9	21.7	21.6	21.7	19.1
August	1500	89.5	90.5	77.6	75.5	24.9	25.1	25.0	24.6
September	0800								
September	1500								

Appendix 5. Influence of soil moisture regime on live shoot weight at harvest.

Soil moisture regime	Variety	Live shoot weight (g/pot)
Zero suction	OS-6	316.5 a
Submergence 20 DAS	OS-6	313.3 a
Submergence 55 DAS	OS-6	274.2 a b
Submergence 35 DAS	OS-6	214.6 a b c
Submergence 35 DAS	IR-20	192.1 b c d
Zero suction	IR-20	166.3 c d e
Submergence 20 DAS	IR-20	155.4 c d e f
500-cm suction	OS-6	150.7 c d e f
250-cm suction	OS-6	149.8 c d e f
750-cm suction	OS-6	120.4 c d e f
250-cm suction	IR-20	120.3 c d e f
Submergence 55 DAS	IR-20	116.0 c d e f
Irrigation at leaf rolling	OS-6	94.5 d e f
500-cm suction	IR-20	71.2 e f
750-cm suction	IR-20	65.2 e f
Irrigation at leaf rolling	IR-20	50.5 f

Appendix 6. Influence of soil moisture regime on dead shoot weight (g/pot).

Soil moisture regime	Variety	Dead shoot weight at harvest (g/pot)
500-cm suction	OS-6	67.6 a
Submergence 35 DAS	IR-20	66.6 a b
750-cm suction	OS-6	59.3 a b c
Zero suction	IR-20	56.7 a b c
Submergence 35 DAS	OS-6	54.0 a b c
Submergence 55 DAS	OS-6	53.2 a b c
Submergence 20 DAS	IR-20	45.6 a b c
Zero suction	OS-6	39.7 a b c
Irrigation at lead rolling	OS-6	33.3 a b c
750-cm suction	IR-20	30.4 a b c
Submergence 20 DAS	OS-6	30.3 a b c
Irrigation at leaf rolling	IR-20	20.8 a b c
Submergence 55 DAS	IR-20	19.7 a b c
250-cm suction	OS-6	15.8 b c
250-cm suction	IR-20	13.7 c
500-cm suction	IR-20	10.4 c

Appendix 7. Influence of soil moisture regime on final plant height.

Soil moisture regime	Variety	Final plant height (cm)
Submergence 55 DAS	OS-6	208.0 a
Submergence 20 DAS	OS-6	204.7 a b
Zero suction	OS-6	202.0 a b c
Submergence 35 DAS	OS-6	170.0 a b c d
Submergence 35 DAS	IR-20	142.0 b c d e
500-cm suction	OS-6	139.0 b c d e
250-cm suction	OS-6	136.3 c d e
750-cm suction	OS-6	135.3 c d e
Irrigation at leaf rolling	OS-6	117.7 d e f
Submergence 20 DAS	IR-20	114.7 d e f
250-cm suction	IR-20	113.3 d e f
Submergence 55 DAS	IR-20	106.0 d e f
Zero suction	IR-20	105.0 d e f
500-cm suction	IR-20	76.3 e f
750-cm suction	IR-20	65.0 f
Irrigation at leaf rolling	IR-20	61.3 f

Appendix 8. Root weight (g/plant) of IR-20 and OS-6 as affected by soil moisture regime.

Soil moisture regime	Variety	Root weight g/plant
Submergence 20 DAS	OS-6	45.7 a
Irrigation at leaf curling	OS-6	41.7 a b
Submergence 35 DAS	OS-6	39.0 a b
Zero suction	OS-6	29.7 a b c
Submergence 35 DAS	IR-20	28.7 a b c
Submergence 55 DAS	OS-6	28.3 a b c
750-cm suction	OS-6	27.7 a b c
Submergence 20 DAS	IR-20	25.7 a b c
Zero suction	IR-20	24.3 a b c
Irrigation at leaf rolling	IR-20	23.0 a b c
Submergence 55 DAS	IR-20	22.0 bc
750-cm suction	IR-20	20.7 b c
500-cm suction	OS-6	14.3 c
250-cm suction	OS-6	11.7 c
250-cm suction	IR-20	8.7 c
500-cm suction	IR-20	7.7 c

Appendix 9. Root perimeter of IR-20 and OS-6 as affected by soil moisture regime.

Soil moisture regime	Variety	Root parimeter (cm)
250-cm suction	OS-6	36.7 a
Submergence 20 DAS	OS-6	36.7 a
Zero suction	OS-6	35.7 a b
Submergence 55 DAS	OS-6	31.3 a b c
Submergence 35 DAS	OS-6	30.3 a b c d
250-cm suction	IR-20	28.5 b c d
Submergence 20 DAS	IR-20	38.3 b c d
Submergence 35 DAS	IR-20	28.3 b c d
Zero suction	IR-20	27.0 c d
500-cm suction	IR-20	26.3 c d
750-cm suction	OS-6	26.0 c d
500-cm suction	OS-6	26.0 c d
Submergence 55 DAS	IR-20	24.0 c d
Irrigation at leaf rolling	OS-6	22.3 d e
750-cm suction	IR-20	15.3 e
Irrigation at leaf rolling	IR-20	15.0 e

Appendix 10. Influence of soil moisture regime on root axis (cm).

Soil moisture regime	Variety	Root axis (cm)
Zero suction	OS-6	12.0 a
Submergence 20 DAS	OS-6	12.0 a
250-cm suction	OS-6	11.7 a b
Submergence 55 DAS	OS-6	10.7 a b c
750-cm Suction	OS-6	10.0 a b c
Submergence 35 DAS	OS-6	10.0 a b c
500-cm suction	OS-6	9.7 a b c
Submergence 35 DAS	IR-20	9.7 a b c
Submergence 20 DAS	IR-20	9.0 b c
250-cm suction	IR-20	8.9 b c
500-cm suction	IR-20	8.7 c
Zero suction	IR-20	8.7 c
Irrigation at leaf rolling	OS-6	8.3 c
Submergence 55 DAS	IR-20	8.0 c d
750-cm suction	IR-20	5.7 d e
Irrigation at leaf rolling	IR-20	5.3 e

Appendix 11. Influence of soil moisture regime and variety on mean root length (cm).

Soil moisture regime	Variety	Mean root length (cm)
Submergence 20 DAS	OS-6	44.3 a
Submergence 55 DAS	OS-6	39.7 a b
750-cm suction	OS-6	36.0 a b c
500-cm suction	OS-6	36.0 a b c
Zero suction	OS-6	36.0 a b c
Irrigation at leaf rolling	OS-6	36.0 a b c
Submergence 35 DAS	OS-6	35.0 a b c
Zero suction	IR-20	35.0 a b c
Submergence 20 DAS	IR-20	35.0 a b c
Submergence 35 DAS	IR-20	34.7 a b c
250-cm suction	OS-6	34.3 b c
Submergence 55 DAS	IR-20	30.7 b c
500-cm suction	IR-20	29.3 c
250-cm suction	IR-20	29.0 c
750-cm suction	IR-20	26.3 c
Irrigation at leaf rolling	OS-6	17.7 d

Appendix 12. Influence of soil moisture regime on the number of days to maturity in IR-20 and OS-6.

Soil moisture regime	Variety	Number of days to maturity
Irrigation at leaf rolling	OS-6	160 a
Irrigation at leaf rolling	IR-20	160 a
750-cm suction	IR-20	155 a
750-cm suction	OS-6	150 a b
500-cm suction	OS-6	145 a b c
500-cm suction	IR-20	130 c
250-cm suction	OS-6	130 c
250-cm suction	IR-20	130 c
Zero suction	OS-6	130 c
Zero suction	IR-20	130 c
Submergence 20 DAS	OS-6	130 c
Submergence 20 DAS	IR-20	130 c
Submergence 35 DAS	OS-6	130 c
Submergence 35 DAS	IR-20	130 c
Submergence 55 DAS	OS-6	130 c
Submergence 55 DAS	IR-20	130 c

Appendix 13. Influence of soil moisture regime and variety on straw yield (g/pot).

Moisture regime	Variety	Straw yield (g/pot)
Zero suction	OS-6	356 a
Submergence 20 DAS	OS-6	343 a b
Submergence 55 DAS	OS-6	327 a b
Submergence 35 DAS	OS-6	268 a b c
Submergence 35 DAS	IR-20	258 a b c
Zero suction	IR-20	223 a b c d
500-cm suction	OS-6	218 a b c d e
Submergence 20 DAS	IR-20	201 b c d e
750-cm suction	OS-6	179 c d e
250-cm suction	OS-6	165 c d e
Submergence 55 DAS	IR-20	135 c d e
250-cm suction	IR-20	134 c d e
Irrigation at leaf rolling	OS-6	128 c d e
750-cm suction	IR-20	95 d e
500-cm suction	IR-20	81 d e
Irrigation at leaf rolling	IR-20	71 e

Appendix 14. Influence of soil moisture regime on floral sterility (%) of IR-20 and OS-6.

Soil moisture regime	Variety	Floral sterility (%)
Irrigation at leaf rolling	OS-6	56 a
Irrigation at leaf rolling	IR-20	40 a b
750-cm suction	IR-20	39 a b
500-cm suction	IR-20	18 b c
500-cm suction	OS-6	12 c
Submergence 35 DAS	IR-20	11 c
750-cm suction	OS-6	9 c
Submergence 55 DAS	IR-20	8 c
Submergence 35 DAS	OS-6	8 c
250-cm suction	OS-6	8 c
Zero suction	OS-6	8 c
Zero suction	IR-20	7 c
250-cm suction	IR-20	7 c
Submergence 20 DAS	IR-20	6 c
Submergence 55 DAS	OS-6	6 c
Submergence 20 DAS	OS-6	6 c

Appendix 15. Influence of soil moisture regime on number of grains/panicle.

Soil moisture regime	Variety	Number of grains/panicle
Submergence 35 DAS	OS-6	173 a
Submergence 20 DAS	OS-6	157 a b
Zero suction	IR-20	143 a b c
Submergence 20 DAS	IR-20	142 a b c
Submergence 55 DAS	OS-6	140 a b c
Zero suction	OS-6	133 a b c d
Submergence 55 DAS	IR-20	127 a b c d e
Submergence 35 DAS	IR-20	117 a b c d e f
250-cm suction	OS-6	102 b c d e f
250-cm suction	IR-20	100 b c d e f
Irrigation at leaf rolling	OS-6	82 c d e f
500-cm suction	OS-6	77 c d e f
Irrigation at leaf rolling	IR-20	77 c d e f
750-cm suction	OS-6	66 d e f
500-cm suction	IR-20	63 e f
750-cm suction	IR-20	56 e f

Appendix 16. Influence of soil moisture regime and variety on panicle length (cm).

Soil moisture regime	Variety	Panicle length (cm)
Submergence 35 DAS	OS-6	29.5 a
Submergence 20 DAS	OS-6	28.8 a b
Submergence 55 DAS	OS-6	27.7 a b
Zero suction	OS-6	26.4 abb c
250-cm suction	OS-6	24.7 a b c d
Zero suction	IR-20	24.4 a b c d
500-cm suction	OS-6	23.8 b c d
Submergence 35 DAS	IR-20	23.8 b c d
Submergence 55 DAS	IR-20	23.[illegible] b c d
250-cm suction	IR-20	23.2 b c d
Submergence 20 DAS	IR-20	23.2 b c d
750-cm suction	OS-6	20.8 c d
500-cm suction	IR-20	20.7 c d
Irrigation at leaf rolling	OS-6	19.8 d
Irrigation at leaf rolling	IR-20	19.5 d
750-cm suction	IR-20	18.9 d

Appendix 17. Influence of soil moisture regime and variety on weight of 1000 grains (g).

Soil moisture regime	Variety	Unit grain weight
Zero suction	OS-6	32.7 a
Submergence 55 DAS	OS-6	31.3 a
Submergence 20 DAS	OS-6	31.0 a
Submergence 35 DAS	OS-6	25.7 a b
500-cm suction	OS-6	25.3 a b
250-cm suction	OS-6	25.0 a b
750-cm suction	OS-6	22.7 a b
Submergence 35 DAS	IR-20	21.7 a b
250-cm suction	IR-20	21.0 a b
Submergence 20 DAS	IR-20	17.0 b c
Zero suction	IR-20	16.0 b c d
Submergence 55 DAS	IR-20	15.0 b c d
500-cm suction	IR-20	14.3 b c d
750-cm suction	IR-20	12.9 b c d
Irrigation at leaf rolling	OS-6	5.4 c d
Irrigation at leaf rolling	IR-20	3.7 d

Appendix 18. Total moisture stress (cm. days) for different soil moisture regimes.

Variety		Soil moisture regime	Soil moisture stress (cm. days)
IR-20		750-cm suction	5809 cm days
IR-20		500-cm suction	4230 "
IR-20		250-cm suction	2625 "
IR-20		Fl. 55 DAS	800 "
IR-20		Fl. 35 DAS	394 "
OS-6		Fl. 35 DAS	360 "
OS-6		Fl. 55 DAS	1150 "
OS-6		250-cm suction	3130 "
OS-6		500-cm suction	5040 "
OS-6		750-cm suction	7570 "
IR-20	Irrigation at leaf curling	-	-

Appendix 19. Total consumptive water use as influenced by soil moisture regime and rice variation (cm).

Soil moisture regime	Consumptive water use (cm)	
	IR-20	OS-6
Submergence 20 DAS		
Submergence 35 DAS	117.10	150.97
Submergence 55 DAS	139.62	189.10
Zero suction	180.80	188.08
250-cm suction	61.26	97.86
500-cm suction	41.11	58.28
750-cm suction	28.52	48.61
Irrigation at leaf rolling		

APPENDICE FOR CHAPTER 4

APPENDIX 4

METHODOLOGY

Greenhouse studies were conducted in 1971 on an Apomu soil of sandy: loam texture containing 70 percent sand, 12 percent silt and 18% clay. The clay fraction of this soil is dominated by Kaolinitic type clay minerals. This soil contains about 1 percent organic carbon has a pH of 6.5 to 6.8. The taxonomy and physical and chemical properties of similar soil series have been described by Moormann et al (1975). The wetting and draining moisture characteristics of the surface soil are shown in Appendix 4.1. A majority of the pores drain between 60 and 100 cm of water suction. The moisture retained at 0.1 bar suction is about 0.16 (gg^{-1}) and that retained at 15 bar suction is 0.05 (gg^{-1}). There is a little change in the moisture retention curve beyond a suction value of 2 bar. Some chemical characteristics of this soil are shown in Appendix 2.

Soil was packed to a bulk density of 1.35 gcm^{-3} in circular metallic containers of 35 cm in diameter, and 36 cm deep. The soil was sieved with a rotary sieve of 8 mesh size prior to packing in these drums. A 2.5 cm thick layer of coarse gravel was maintained at the bottom of the drum to facilitate drainage. A detailed sketch of the set up to regulate water regime in these containers is shown in Fig. 2, and Plate I and R.II. The application of water was regulated by observing soil water suction at the pre-determined depth. When necessary, water application was made through sub-surface irrigation using a perforated irrigation tube of 2.5 cm diameter and positioned in the centre of the container (Fig. 2). Fertilizer application at planting was made at the rate of 100 ppm of P as single super-phosphate, 50 ppm of K as umurate of potash, and 60 ppm of N as urea. This fertilizer was mixed in the entire soil volume before packing. Top dressing with N was made at the rate of 60 and 80 ppm of N applied at 6-weeks and at early heading stage of rice growth.

Eight seeds, rice varieties IR-20 and OS-6, were planted in each container in dry soil on 20th May, 1971. The soil moisture suction at planting was approximately 150 cm of water suction. Seedlings, after emergence, were thinned to four per pot.

Two varieties investigated in this experiment were those known for their high yield potential in West African conditions. OS-6 is a tall, leafy, disease-resistant variety widely grown as upland rice in West Africa. It has a good seedling vigor, a superior root system, and has bold long grain of acceptable quality but tends to be low tillering and lodges easily under improved management.

IR-20 is a dwarf erect-leaved, high tillering, stiff strawed variety from IRRI. This variety has a superior resistance to disease and a substantial tolerance to major insect pests. It is slightly later maturing than OS-6, and has a small, slender grain of good milling quality.
qu

The comparison of yield and growth parameters of these two rice varieties was investigated at eight levels of soil moisture regimes. These moisture regimes were, continuous submergence of 5 cm depth from 20, 35 and 55 days after planting (DAP), saturated soil with no submergence, and soil moisture suction of 250, 500 and 750 cm of water maintained at a 15-cm depth throughout the growing season. One treatment consisted of irrigating only when plants showed signs of wilting at 1400 hour. Soil moisture suction was read three times a day and containers were irrigated with the desired quantity of water for each treatment.

The temperature under the greenhouse conditions ranged from 22 to 32°C and the relative humidity from 70 to 100 percent. The data of evaporation from free water surface is shown in Table 2, and the weekly average temperature and humidity records are shown in Table 3.

Each of the 16 treatments (Two varieties x 8 moisture levels) was replicated four times. All 64 containers were completely randomized. One plant from the fourth replication was harvested four times during the growth stages to assess the dry matter production.

Periodic observations were made for plant height, tiller count, dry matter production, nutrient uptake by tissue analysis. Yield and yield components were analysed at harvest. Leaf area was determined by direct measurement using a shape factor for each variety.

The shape factor was determined for leaves of different ages and was experimentally found to be 0.71 for OS-6 and 0.77 for IR-20. After the crop was harvested, the soil was carefully washed off the roots. The root length was determined immediately after washing, while the dry weight was

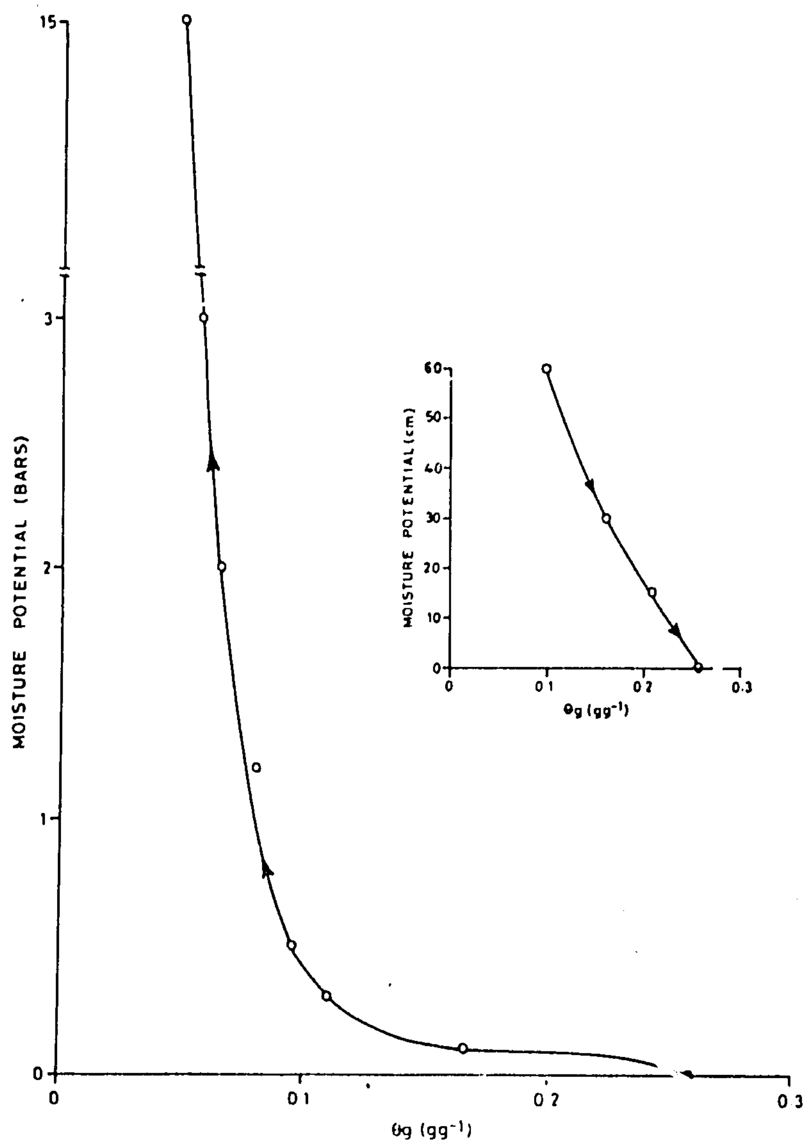

Fig.1. Wetting and draining soil moisture characteristics of the surface soil.

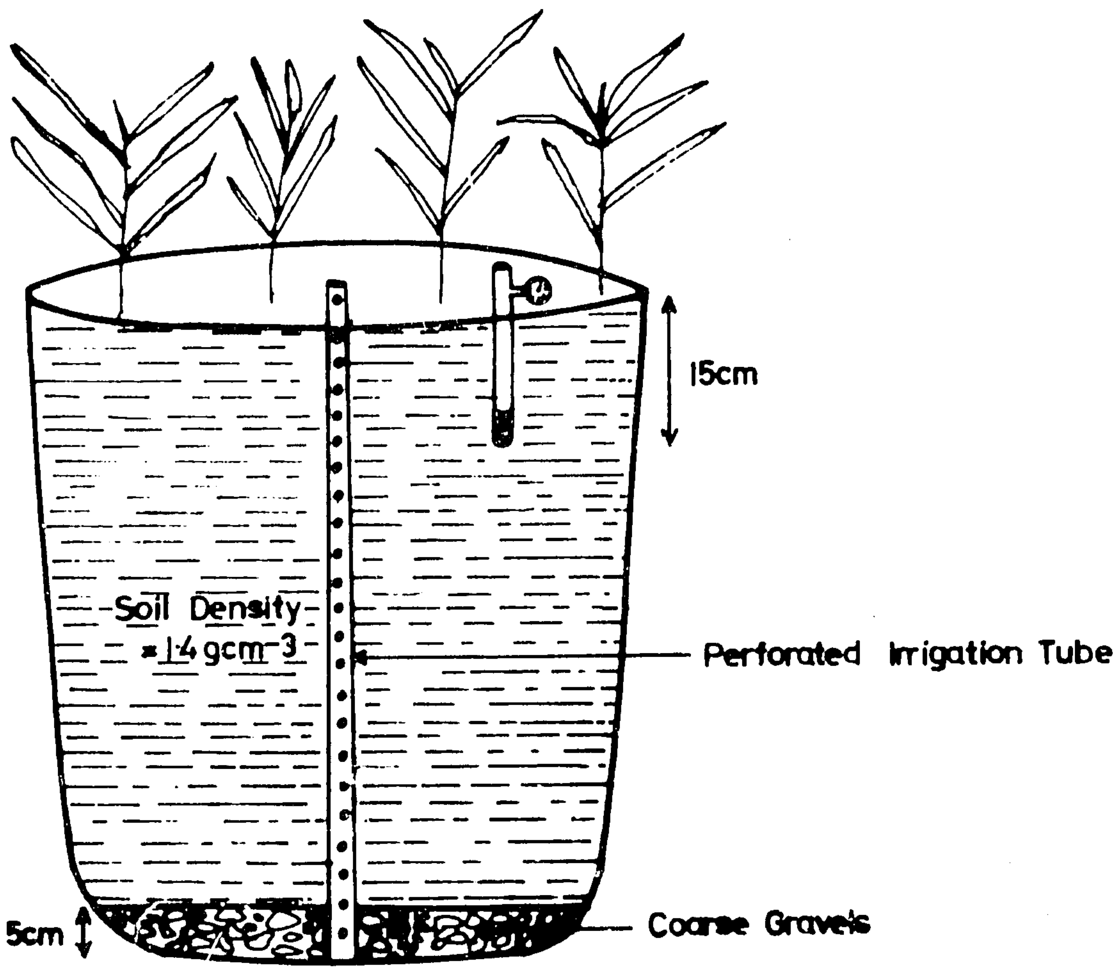

Fig.2. Method of water application.

APPENDICES FOR CHAPTERS 5 to 8

APPENDIX 5

METHODOLOGY

The influence of soil moisture stress under field conditions was investigated in the lysimeters described in Chapter 3. These experiments were conducted in the dry season from November 1971 to March 1972.

The treatments were imposed according to a completely randomized design. Vacuum gauge tensiometers were installed in each lysimeter at 15 cm depth. The tensiometric readings were monitored at 0730 and 1330 hour daily. A known quantity of water was then added to each lysimeter, depending on the tensiometric measurements and soil moisture characteristics. Daily fluctuations in soil moisture potential are shown in the Appendix.

Pre-soaked seeds of IR-20 were broadcast in shallow water in the lysimeters and surrounding field on November 19, 1971. A uniform fertilizer application was made to all the lysimeters and surrounding areas. Nitrogen was applied in a split application at the rate of 60 kg/ha. One-third (44 kg urea/ha) was applied 20 DAS, 42 DAS, and 70 DAS. Phosphorus was applied at 26 kg P per hectare and K at 15 kg/ha. Insect control was obtained by spraying Vetox 85 at 1 kg/ha (1.2 kg dissolved in 500 hectare).

Periodic observations were made for plant height and tiller count. The yield and yield components were monitored at maturity. Rice was harvested on 16th March, 1972.

APPENDIX 6

METHODOLOGY

Sieved surface soil of Apomu series was packed in containers, 35 cm in diameter and 36 cm deep. The soil was packed at a dry bulk density of 1.35 gcm^{-3}, leaving upper 5 cm unpacked for facilitating irrigation and submergence. Perforated irrigation tubes of 2.5 cm diameter were installed in the centre of the drum to apply water from the sub-surface for even distribution.

Twelve seeds of two rice varieties, IR-20 and OS-6, were planted in each container on May 17, 1972. After germination, seedlings were thinned to four per container, fertilizer application were made at the rate of 4.5 g urea per pot at the time of planting, and 4.5 g and 6.0 g later at 6 and 9 weeks after planting, respectively.

Soil moisture suction was monitored by using vacuum gauge dial type tensiometers. Suction observations were made 3 times a day and irrigation with the required amount of water was done depending on the tensiometric readings and the soil moisture characteristics. All treatments were replicated thrice, and the pots were distributed as stipulated by the completely randomized design.

APPENDIX 8

Each treatment was replicated four times, and the containers (dimensions described in the previous section) were spaced according to a completely randomized design.

Rice was seeded on 23rd October, 1972. The nitrogenous fertilizer was applied as follows:

(i) 4.5 g urea/pot 2 weeks before seeding

(ii) 4.5 g urea/pot 3 weeks after seeding

(iii) 6.0 g urea/pot 6 weeks after seeding.

Soil moisture suction was monitored by installing vacuum gauge. Tensiometer at 0730, 1000, and 1300 daily. A known quantity of irrigation water was added, according to soil moisture suction, and the soil moisture characteristics.

APPENDICES FOR CHAPTER 11

Appendix 1. Influence of soil moisture regime and nitrogen levels on plant height 25 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	38.0	52.0	38.7	50.3	36.7	48.7	35.7	49.0
100-cm suction	37.7	53.3	36.0	50.0	35.7	48.0	31.7	43.0
250-cm suction	36.7	48.7	37.3	50.7	36.3	46.0	30.0	44.3
LSD (.05)								
(i) Moisture	1.7							
(ii) Nitrogen	1.7							
(iii) Variety	1.5							

Appendix 2. Influence of soil moisture regime and nitrogen levels on plant height 32 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	51.7	74.0	53.3	72.0	50.7	70.0	49.3	71.0
100-cm suction	46.3	74.3	43.3	72.0	43.0	67.3	38.7	62.3
250-cm suction	41.0	66.0	42.0	68.0	41.0	64.0	34.3	62.0
LSD (.05)								
(i) Moisture	2.2							
(ii) Nitrogen	1.9							
(iii) Variety	1.7							

Appendix 3. Influence of soil moisture regime and nitrogen levels on plant height 39 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	60.0	84.7	60.3	86.0	58.0	86.7	61.7	88.7
100-cm suction	58.3	95.7	57.3	92.3	55.0	87.3	48.0	83.3
250-cm suction	49.3	84.3	46.0	89.0	49.3	83.7	42.0	81.0
LSD (.05)								
(i) Moisture	4.5							
(ii) Nitrogen	1.9							
(iii) Variety	1.9							

Appendix 4. Influence of soil moisture regime and nitrogen levels on plant height 46 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	68.3	97.3	67.7	99.7	71.7	103.7	70.7	104.3
100-cm suction	66.7	112.3	64.7	106.7	61.7	102.7	51.7	96.0
250-cm suction	60.0	100.0	55.7	102.7	58.0	94.0	44.0	92.3
LSD (.05)								
(i) Moisture	4.0							
(ii) Nitrogen	2.7							
(iii) Variety	1.8							

Appendix 5. Influence of soil moisture regime and nitrogen levels on plant height 54 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	77.3	114.7	83.0	117.0	79.3	117.0	77.7	118.0
100-cm suction	74.3	127.3	70.0	125.7	66.7	118.7	53.3	111.0
250-cm suction	63.3	112.0	59.0	116.0	61.7	105.7	49.3	98.3
LSD (.05)								
(i) Moisture	3.2							
(ii) Nitrogen	4.2							
(iii) Variety	2.1							

Appendix 6. Influence of soil moisture regime and nitrogen levels on plant height 62 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	87.0	112.7	93.7	128.3	89.7	127.0	91.0	126.7
100-cm suction	80.3	129.0	75.7	133.0	73.7	126.0	56.7	122.7
250-cm suction	68.7	120.0	62.7	125.7	65.3	122.7	49.7	107.3

LSD (.05)	
(i) Moisture	2.5
(ii) Nitrogen	3.6
(iii) Variety	1.8

Appendix 7. Influence of soil moisture regime and nitrogen levels on plant height 70 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	90.0	124.0	96.7	134.0	91.7	131.3	96.3	130.7
100-cm suction	74.7	129.7	82.0	138.7	79.3	130.7	59.7	130.0
250-cm suction	71.3	121.7	65.3	128.3	66.7	123.0	53.7	115.3
LSD (.05)								
(i) Moisture	4.5							
(ii) Nitrogen	3.2							
(iii) Variety	2.2							

Appendix 8. Influence of soil moisture regime and nitrogen levels on plant height 77 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	91.7	127.7	98.3	137.0	93.3	131.7	96.0	131.7
100-cm suction	86.7	131.0	83.0	141.0	82.3	134.0	61.0	132.3
250-cm suction	72.7	124.0	66.7	131.0	67.3	126.7	54.0	116.3
LSD (.05)								
(i) Moisture	4.05							
(ii) Nitrogen	2.80							
(iii) Variety	2.0							

Appendix 9. Influence of soil moisture regime and nitrogen levels on plant height 110 days after seeding (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	105.7	186.0	102.7	190.0	103.7	200.3	106.3	194.7
100-cm suction	100.0	171.0	89.0	192.0	84.3	141.3	59.7	174.0
250-cm suction	71.7	127.7	71.3	105.3	56.7	120.3	53.7	116.3
LSD (.05)								
(i) Moisture	17.0							
(ii) Nitrogen	11.0							
(iii) Variety	7.7							

Appendix 12. Influence of soil moisture regumes and nitrogen rates on tillers/plant, 18 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	3	2.0	2.7	2.0	2.7	1.7	2.7	1.7
100-cm suction	2.7	2.0	2.3	1.7	2.7	2.0	2.3	1.3
250-cm suction	2.7	2.0	2.7	2.0	3.0	2.0	1.3	2.0
LSD (.05)								
(i) Moisture	0.37							
(ii) Nitrogen	0.31*							
(iii) Variety	0.25**							

Appendix 13. Influence of soil moisture regime and nitrogen rates on tillers/plant, 35 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	7.0	3.7	7.0	4.3	6.0	3.0	5.0	3.7
100-cm suction	6.3	4.7	6.7	4.0	6.7	4.0	5.3	3.0
250-cm suction	5.3	4.0	6.3	4.0	6.7	3.7	4.3	3.3
LSD (.05)								
(i) Moisture	0.51							
(ii) Nitrogen	0.55							
(iii) Variety	0.46							

Appendix 14. Influence of soil moisture regime and nitrogen levels on tillers/plant 30 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	8.7	4.7	9.0	5.7	8.7	5.0	8.7	5.7
100-cm suction	9.3	6.0	9.3	4.7	9.7	5.0	8.3	3.7
250-cm suction	7.0	4.3	8.7	4.3	9.3	4.0	6.0	4.0
LSD (.05)								
(i) Moisture	0.71							
(ii) Nitrogen	0.72							
(iii) Variety	0.60							

Appendix 15. Influence of soil moisture regime and nitrogen levels on tillers/plant 37 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	12.7	6.3	12.0	7.7	14.7	7.7	14.3	8.7
100-cm suction	14.7	8.3	15.0	7.3	14.0	6.7	11.7	6.7
250-cm suction	12.7	6.0	12.0	6.0	14.0	5.7	9.3	5.7
LSD (.05)								
(i) Moisture	2.1							
(ii) Nitrogen	1.1							
(iii) Variety	1.0							

Appendix 16. Influence of soil moisture regime and level of nitrogen on tillers/plant 45 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	17.3	6.7	16.0	8.0	19.0	8.0	18.3	9.7
100-cm suction	19.7	9.7	19.3	9.3	19.7	9.3	16.3	8.7
250-cm suction	16.0	10.7	17.3	8.0	18.0	7.3	12.3	7.0
LSD (.05)								
(i) Moisture	1.4							
(ii) Nitrogen	1.3							
(iii) Variety	1.0							

Appendix 17. Influence of soil moisture regime and nitrogen rates on tillers/plant 52 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	23.7	9.7	24.7	13.0	25.7	11.7	21.0	13.3
100-cm suction	25.0	9.7	24.3	11.0	25.7	11.3	18.3	12.7
250-cm suction	21.7	13.0	21.0	10.0	21.0	8.3	16.7	8.0
LSD (.05)								
(i) Moisture	1.7							
(ii) Nitrogen	2.0							
(iii) Variety	1.4							

Appendix 18. Influence of soil moisture regime and nitrogen rate on tillers/plant 59 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	26.0	10.0	28.9	15.0	31.3	14.0	27.3	15.0
100-cm suction	30.0	11.3	32.7	14.0	33.7	15.7	27.0	12.7
250-cm suction	23.7	11.3	27.7	14.7	29.0	10.3	21.0	11.0
LSD (.05)								
(i) Moisture	2.0							
(ii) Nitrogen	1.6							
(iii) Variety	1.2							

Appendix 19. Influence of soil moisture regime and nitrogen level on tillers/plant 66 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	28.3	11.0	30.7	15.7	30.7	14.3	31.3	16.0
100-cm suction	37.0	13.0	39.3	15.0	41.7	19.0	35.3	13.7
250-cm suction	32.3	12.3	32.3	14.7	35.0	12.7	24.6	11.7
LSD (.05)								
(i) Moisture	1.5							
(ii) Nitrogen	1.7							
(iii) Variety	1.3							

Appendix 20. Influence of soil moisture regime and nitrogen levels on tillers /plant 72 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	30.7	11.0	34.7	15.7	36.3	14.7	34.3	15.3
100-cm suction	40.7	12.3	46.7	15.7	48.0	19.7	36.3	15.0
250-cm suction	33.7	13.0	39.0	16.0	40.3	12.7	26.3	12.7
LSD (.05)								
(i) Moisture								
(ii) Nitrogen								
(iii) Variety								

Appendix 21. Influence of soil moisture regime and nitrogen levels on tillers/plant 95 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	31.7	11.0	38.0	15.0	48.0	14.3	45.7	15.7
100-cm suction	41.7	13.3	54.0	15.3	63.0	22.3	56.7	18.7
250-cm suction	46.0	14.3	48.3	18.3	54.0	16.7	42.3	15.0
LSD (.05)								
(i) Moisture	1.9							
(ii) Nitrogen	3.8							
(iii) Variety	2.2							

Appendix 22. Influence of soil moisture regime and nitrogen level on dry straw weight (g/plant), 20 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	0.21	0.290	0.22	0.23	0.197	0.160	0.180	0.237
100-cm suction	0.227	0.230	0.137	0.153	0.190	0.207	0.167	0.147
250-cm suction	0.183	0.243	0.243	0.320	0.220	0.280	0.210	0.197
LSD (.05)								
(i) Moisture	n.s							
(ii) Nitrogen	n.s							
(iii) Variety	n.s							

Appendix 23. Influence of soil moisture regime and nitrogen level on dry straw weight (g/plant), 40 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	8.30	4.58	7.59	6.57	4.67	4.53	5.25	5.49
100-cm suction	3.56	3.51	3.97	2.23	3.74	4.26	2.54	2.78
250-cm suction	2.63	2.08	2.46	4.32	2.83	3.06	1.26	3.21
LSD (.05)								
(i) Moisture	1.39							
(ii) Nitrogen	n.s							
(iii) Variety	n.s							

Appendix 24. Influence of soil moisture regime and nitrogen levels on dry straw weight (g/plant), 54 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	19.63	17.07	21.45	17.52	16.37	24.29	11.30	21.93
100-cm suction	13.80	22.09	12.17	18.15	10.27	18.81	4.60	12.15
250-cm suction	9.49	14.03	8.72	11.62	6.76	12.62	4.87	6.90
LSD (.05)								
(i) Moisture	3.55							
(ii) Nitrogen	2.95							
(iii) Variety	1.84							

Appendix 25. Influence of soil moisture regime and nitrogen levels on straw weight (g/plant), 62 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	35.19	32.40	45.98	37.69	54.58	36.56	38.77	53.91
100-cm suction	21.94	26.66	18.19	26.69	15.98	26.39	8.26	28.07
250-cm suction	15.02	25.74	18.12	29.85	13.27	19.22	5.81	10.42
LSD (.05)								
(i) Moisture	7.34							
(ii) Nitrogen	6.73							
(iii) Variety	5.13							

Appendix 26. Influence of soil moisture regime and nitrogen levels on dry straw weight)g/plant), 90 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	111.3	83.1	91.5	105.4	118.6	112.3	99.6	156.3
100-cm suction	69.3	68.2	77.5	94.2	74.3	146.3	32.9	90.6
250-cm suction	54.2	71.3	46.5	68.8	53.1	49.3	10.4	28.8
LSD (.05)								
(i) Moisture	7.21							
(ii) Nitrogen	19.39							
(iii) Variety	13.69							

Appendix 27. Influence of soil moisture regime and nitrogen levels on dry straw weight (g/plant), 110 days after seeding.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	97.7	155.3	222.0	327.0	389.0	518.3	379.3	426.3
100-cm suction	207.7	255.3	230.3	420.7	271.7	476.7	196.0	427.3
250-cm suction	166.0	268.0	173.3	327.0	164.3	270.3	69.0	128.7
LSD (.05)								
(i) Moisture	49.5							
(ii) Nitrogen	45.0							
(iii) Variety	39.5							

Appendix 28. Influence of soil moisture regimes and levels of nitrogen on grain yield of IR-20 and OS-6.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	185.9	181.6	222.6	233.4	283.2	263.5	302.9	255.0
100-cm suction	150.9	176.1	185.0	199.4	98.9	83.0	13.9	121.2
250-cm suction	60.0	54.0	47.8	33.1	16.2	15.0	0.0	5.1
LSD (.05)								
(i) Moisture	27.6							
(ii) Nitrogen	20.7							
(iii) Variety	11.5							

Appendix 29. Unit grain weight (g/100 grains) of IR-20 and OS-6 as influenced by nitrogen levels and soil moisture regimes.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	1.96	3.62	1.59	3.54	1.91	3.46	1.53	3.34
100-cm suction	1.83	3.43	1.86	3.37	1.55	1.94	0.42	3.14
250-cm suction	1.47	2.93	0.91	1.02	0.44	0.90	0.00	0.00
LSD (.05)								
(i) Moisture	0.58							
(ii) Nitrogen	0.51							
(iii) Variety	0.32							

Appendix 30. Influence of soil moisture regime and nitrogen levels on percentage of filled grains.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	94.3	92.7	92.6	89.6	93.1	93.6	93.4	96.7
100-cm suction	95.0	88.0	92.9	87.4	76.8	42.7	43.0	67.5
250-cm suction	57.8	70.1	49.3	27.7	29.1	23.8	0.00	0.00
LSD (.05)								
(i) Moisture	11.6							
(ii) Nitrogen	13.1							
(iii) Variety	0.6							

Appendix 31. Influence of soil moisture regime and levels of nitrogen application on panicle weight (kg/pot).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	0.223	0.253	0.257	0.243	0.230	0.263	0.233	0.250
100-cm suction	0.193	0.237	0.170	0.287	0.370	0.160	0.063	0.187
250-cm suction	0.113	0.140	0.080	0.130	0.083	0.107	0.00	0.030
LSD (.05)								
(i) Moisture	0.047							
(ii) Nitrogen								
(iii) Variety								

Appendix 32. Influence of soil moisture regime and levels of N application on number of sterile grains/panicle.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	9.0	10.7	12.7	16.0	11.0	11.0	9.0	7.3
100-cm suction	9.3	17.7	5.3	19.3	16.3	45.0	23.3	35.7
250-cm suction	35.7	28.0	30.0	49.3	46.3	48.0	All	18.7
LSD (.05)								
(i) Moisture	6.5							
(ii) Nitrogen	9.8							
(iii) Variety	5.4							

Appendix 33. Influence of soil moisture regime and levels of N application on panicle length (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	23.8	28.8	26.3	30.5	27.5	29.8	26.9	31.2
100-cm suction	34.2	29.5	27.2	30.0	24.9	25.6	19.0	26.2
250-cm suction	21.8	22.5	21.7	20.5	20.6	22.5	0.00	7.1

LSD (.05)	
(i) Moisture	4.27
(ii) Nitrogen	2.92
(iii) Variety	2.08

Appendix 34. Influence of soil moisture regime and levels of N on grain weight/panicle (g).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	2.98	5.43	2.92	4.81	2.79	4.97	2.82	4.95
100-cm suction	2.48	4.42	1.80	4.63	0.84	1.35	0.26	2.40
250-cm suction	0.74	1.74	0.45	0.88	0.62	0.60	0.00	0.09
LSD (.05)								
(i) Moisture	0.27							
(ii) Nitrogen	0.48							
(iii) Variety	0.27							

Appendix 35. Influence of soil moisture regime and nitrogen levels on root length (cm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	33.5	54.9	38.8	56.6	40.2	49.6	36.0	59.6
100-cm suction	32.0	35.6	35.1	38.4	38.8	53.8	36.6	46.8
250-cm suction	54.0	51.4	44.3	49.5	39.0	44.7	17.6	38.6
LSD (.05)								
(i) Moisture	7.1							
(ii) Nitrogen	7.7							
(iii) Variety	5.5							

Appendix 36. Influence of soil moisture regime and nitrogen levels on root diameter (mm).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	1.97	2.23	1.93	2.63	2.73	3.07	2.40	2.23
100-cm suction	1.50	1.93	2.20	2.17	2.13	2.37	1.57	2.03
250-cm suction	2.07	2.47	1.93	2.47	1.60	2.30	1.17	1.07
LSD (.05)								
(i) Moisture	0.43							
(ii) Nitrogen	0.38							
(iii) Variety	0.18							

Appendix 37. Influence of soil moisture regime and nitrogen levels on dry root weight g/plant.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	40.6	36.6	55.9	58.9	66.1	73.4	[illegible].7	42.9
100-cm suction	17.8	17.5	15.9	45.5	59.5	69.3	15.1	33.7
250-cm suction	20.0	52.3	18.0	65.8	16.2	27.6	6.6	13.7
LSD (.05)								
(i) Moisture	20.2							
(ii) Nitrogen	15.8							
(iii) Variety	10.9							

Appendix 38. Influence of soil moisture regime and nitrogen level on root weight of 3-cm section.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	5.23	3.49	5.61	6.49	8.55	6.73	8.24	4.98
100-cm suction	1.80	2.06	2.26	3.82	3.08	4.08	1.53	3.85
250-cm suction	2.29	4.93	2.47	4.33	1.84	3.44	1.78	2.05
LSD (.05)								
(i) Moisture	1.89							
(ii) Nitrogen	1.61							
(iii) Variety	0.59							

Appendix 39. Influence of soil moisture regime and nitrogen level on root number.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	722	537	976	853	756	722	825	891
100-cm suction	470	693	486	310	649	654	230	492
250-cm suction	541	653	716	501	594	739	309	313
LSD (.05)								
(i) Moisture	ns							
(ii) Nitrogen	ns							
(iii) Variety	ns							

Appendix 40. Leaf water potential (L_ψ) at 50% flowering (Bars) at 8 a.m.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	16.7	10.7	15.6	13.7	15.3	13.8	15.7	12.9
100-cm suction	15.4	12.9	18.0	13.4	17.7	13.2	-	15.4
250-cm suction	20.7	13.1	19.1	16.6	12.3	5.9	9.2	-
LSD (.05)								
(i) Moisture	6.6							
(ii) Nitrogen	3.0							
(iii) Variety	1.9							

Appendix 41. Leaf water potential (L_{ψ}) at 50% flowering (Bars) at 11 a.m.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	18.0	18.7	17.5	17.1	18.4	14.8	19.6	16.0
100-cm suction	19.6	16.3	21.4	15.6	17.9	19.6	-	17.5
250-cm suction	21.1	15.3	20.8	18.5	14.6	6.0	9.6	-
LSD (.05)								
(i) Moisture	6.7							
(ii) Nitrogen	3.3							
(iii) Variety	2.0							

Appendix 42. Leaf water potential (L_ψ) at 50% flowering (Bars), at 1400 hour.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	21.0	20.7	21.7	20.8	19.5	19.2	21.2	18.3
100-cm suction	21.5	19.4	21.7	18.0	22.2	20.9	-	19.7
250-cm suction	22.9	20.6	23.3	20.8	15.9	7.1	9.8	-
LSD (.05)								
(i) Moisture	6.6							
(ii) Nitrogen	3.8							
(iii) Variety	2.2							

Appendix 43. Leaf water potential (L_ψ) (Bars), at grain filling stage at 0800 hour.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	17.3	12.6	16.0	13.0	15.2	13.9	16.3	14.2
100-cm suction	17.7	15.0	16.1	14.0	6.9	4.5	-	9.9
250-cm suction	-	6.0	12.6	5.6	5.5	-	-	-

LSD (.05)

(i)	Moisture	4.2
(ii)	Nitrogen	3 8
(iii)	Variety	n.s

Appendix 44. Leaf water potential (Bars) at grain filling stage at 1100 hour.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	17.3	14.6	18.7	17.8	18.9	17.8	18.3	16.7
100-cm suction	18.8	16.8	21.9	16.8	7.5	6.4	-	13.0
250-cm suction	-	6.2	16.3	6.9	7.8	-	-	-
LSD (.05)								
(i) Moisture	5.1							
(ii) Nitrogen	4.7							
(iii) Variety	n.s							

Appendix 45. Leaf water potential (L_{ψ}) at grain filling stage at 1400 hour (Bars)

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	21.0	13.2	20.2	13.3	20.7	12.6	20.1	10.9
100-cm suction	19.8	18.4	23.1	19.2	7.5	6.1	-	7.6
250-cm suction	-	6.9	16.9	6.9	8.5	-	-	-
LSD (.05)								
(i) Moisture	3.5							
(ii) Nitrogen	4.8							
(iii) Variety	n.s							

Appendix 46. Influence of nitrogen level and soil moisture regime on the leaf water potential (PSI) at 50% flowering stage of growth.

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	277.3	243.3	265.0	249.7	257.7	231.7	274.3	228.0
100-cm suction	273.7	235.7	296.0	228.0	279.3	259.7	-	255.3
250-cm suction	313.0	237.3	306.0	271.3	207.0	92.3	138.0	130.0

LSD (.05)

(i)	Moisture	130
(ii)	Nitrogen	67.5
(iii)	Variety	15.0

Appendix 47. Leaf diffusive resistance at panicle initiation stage (sec cm^{-1}).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	4.55	5.22	4.52	5.08	4.22	5.77	3.93	5.56
100-cm suction	2.97	3.99	2.94	3.77	3.26	3.72	4.33	3.40
250-cm suction	3.96	6.03	9.63	5.85	4.96	6.04	15.64	8.82

LSD (.05)	
(i) Moisture	3.41
(ii) Nitrogen	1.45
(iii) Variety	0.91

Appendix 48. Leaf diffusive resistance at mid-tillering stage (sec cm^{-1}).

Soil moisture regime	100 ppm N		200 ppm N		300 ppm N		400 ppm N	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
Submergence	3.48	3.90	4.09	3.83	3.60	4.00	3.52	3.92
100-cm suction	3.61	4.26	4.38	4.39	4.81	5.17	7.48	4.08
250-cm suction	5.20	4.91	5.41	4.25	4.38	4.68	5.68	5.36
LSD (.05)								
(i) Moisture	1.47							
(ii) Nitrogen	0.47							
(iii) Variety	0.30							

Appendix 49. Leaf moisture potential (L_ψ) monitored 3 days after 3rd doze of fertilizer application (Bars).

Treatments	Leaf water potential (PSI)					
	8.30 am		11 am		2 pm	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
M_1 N_1	260	165	270	260	310	365
M_1 N_4	230	150	240	205	295	275
M_3 N_1	265	190	335	290	390	385
M_3 N_4	300	245	405	250	430	325

Appendix 50. Leaf diffusive resistance at 3 days after 3rd application of fertilizer (sec cm^{-1}).

Treatments	Leaf resistance sec. cm^{-1}					
	8.30 am 8.30 am		11 am 8.1300		2 pm 2 pm	
	IR-20	OS-6	IR-20	OS-6	IR-20	OS-6
M_1 N_1	2.71	3.53	3.31	4.40	4.49	5.64
M_1 N_4	2.77	3.23	3.87	4.75	4.61	6.01
M_3 N_1	3.69	3.46	4.38	4.85	5.47	5.69
M_3 N_4	5.26	5.16	7.38	7.24	8.77	13.47